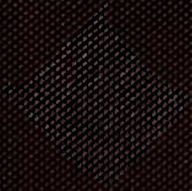

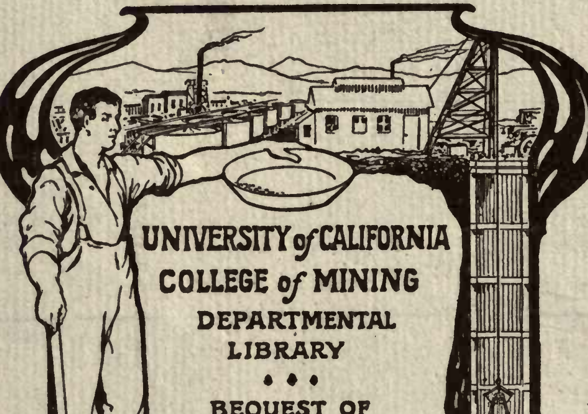

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MIXED METALS

OR

METALLIC ALLOYS

BY

ARTHUR H. HIORNS

PRINCIPAL,

SCHOOL OF METALLURGY, BIRMINGHAM AND MIDLAND INSTITUTE

London
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PREFACE

As a teacher of metallurgy, living and working amongst Birmingham people, it is not surprising that the subject of metallic alloys has claimed a considerable amount of the author's attention, seeing that Birmingham is the very centre of what may be termed the mixed-metals trades.

A work adequate to the importance of the subject has yet to be written, for our knowledge of the phenomena which attend the union of metals is still very imperfect, and rests upon a comparatively slender experimental basis. But it is hoped that the present volume may at least supply a want which is becoming increasingly felt by practical men, as well as by a large number of students, who desire a more intimate acquaintance with the nature and properties of metals in the alloyed state, as well as with metals in the free state.

The author has aimed at taking up the subject where ordinary metallurgical treatises leave off, dealing with the metals in a state of admixture with each other, showing how such mixtures are usefully employed. In cases, which have come under the author's notice, where the properties of certain alloys have been investigated by eminent men, who may be taken as authorities on the subject, an abstract of their researches is given in the succeeding pages, and, as far

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as possible, the source of the information is duly acknowledged. In some instances where knowledge appeared to be lacking, such as in German silver, for example, the author has endeavoured to supply the deficiency by experiments of his own, as well as to test the accuracy of some published statements which appeared to him doubtful.

It has been thought advisable to give a brief account of the main properties of the separate metals, and of the effect of certain elements upon them, seeing that commercial metals are not chemically pure substances, and that the presence of the common impurities often produces a characteristic result, which may be a useful guide to the manufacturer in special cases, and assist him to determine the cause of those anomalies which are constantly occurring in practice.

As many persons engaged in the melting and mixing of metals are not very familiar with chemical processes, a short account of chemical terms and principles, and of a few of the non-metallic elements, is given for their guidance.

The author has experienced considerable difficulty in dealing with the various alloys in a systematic manner without repetition, but hopes that, with the aid of the copious index, any given alloy may be easily referred to.

The first portion deals with the principal chemical elements, and their classification into suitable groups; the refractory materials used in making crucibles and in furnace construction; as well as the properties and uses of various fluxes. The alloys themselves are arranged in the following order:—

I. Copper alloys, including brass and bronze.
II. Nickel alloys, including German silver.
III. Tin alloys, including soft solder, fusible metal, and Britannia metal.

IV. Lead alloys, including pewter and shot metal.
V. Mercury alloys or amalgams.
VI. Alloys of precious metals, including gold, silver, and platinum.
VII. Iron alloys.
VIII. Miscellaneous alloys.

Under one or other of the above headings will be found alloys containing the metals platinum, silver, gold, mercury, copper, lead, cadmium, bismuth, tin, antimony, arsenic, iron, aluminium, chromium, nickel, cobalt, manganese, tungsten, titanium, sodium, potassium, and magnesium.

BIRMINGHAM AND MIDLAND INSTITUTE,
October 1890.

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CHAPTER I

INTRODUCTION

§ 1. That metals are capable of uniting with each other to form a series of bodies, having more or less the properties of their constituents, has long been known, and probably this knowledge has been usefully applied from remote antiquity. The ancients were acquainted with seven metals, viz. gold, silver, mercury, copper, iron, tin, and lead. They knew and employed various compounds of antimony, arsenic, and zinc; although we have no evidence that these metals were known to them in the metallic state.

Gold and silver, which occur in nature in the metallic state, were probably the first metals with which man became acquainted, and as other metals were discovered, especially copper, attempts would doubtless be made to alloy the base metals with gold, in consequence of the comparative rarity of the latter. Copper is also occasionally found "native," and to persons accustomed to melt the precious metals, there would be no difficulty in melting copper and alloying it with gold and silver.

The Latin word *aes* in ancient writings sometimes signifies copper, and sometimes brass, so that the two metals were occasionally confounded together. Pliny says, "that an ore of *aes*, termed chalcitis, occurs in Cyprus, where *aes* was first discovered." Here *aes* obviously means copper. In another place he says that *aes* is obtained from a mineral called *cadmia*. Now cadmia is the ore known at the present time as calamine, which is chiefly a carbonate of zinc. This substance, when mixed with charcoal, and strongly heated for some time in a closed crucible in admixture with metallic copper, or with an oxide of copper, forms brass. The proper name for brass was *aurichalcum*, or golden copper, and it may be inferred that ores of copper and zinc were sometimes smelted together forming brass, as the metal zinc in the free state was probably unknown till the sixteenth century. Pliny describes four different varieties of what was known as Corinthian copper.

1. White. It resembles silver in lustre and contains an excess of that metal.
2. Red. In this kind there is an excess of gold.
3. In this kind, gold, silver, and copper are mixed in equal proportions.
4. This variety was termed *hepatizon*, from its having a liver colour, which gives it its value.

Copper was used by the ancients for many of the purposes to which it is put by the moderns. The alloys of copper with tin were used in various proportions, thus: bronze for statues was composed of 100 parts copper and 12½ parts tin. Another mixture was 100 parts copper, 10 parts lead, and 5 parts tin. Culinary pots were made of an alloy of 100 parts copper and 3 to 4 parts tin. The arms of the ancients were often made of bronze, which was rendered hard by heating and allowing to cool slowly.

Tin was in common use in the time of Moses. It was doubtless the Phœnicians who supplied the Egyptians with this metal, which the former obtained from the Scilly islands and Cornwall. Cassiteros, or tin, is mentioned by Homer. In the time of Pliny, tin was used for coating the interior of copper and brass vessels.

Mercury was used by the Romans for alloying with gold and silver to form amalgams, which were used for gilding and plating, as at the present time, by laying the amalgam on the base metals, and subsequently volatilising the mercury by heat, leaving a thin coating of the precious metal on the article.

Lead was well known to the ancient Egyptians, as well as to the Romans, by whom it was termed *plumbum nigrum*. Large quantities of lead were obtained from Spain and Britain. Sheet lead and lead piping were used for similar purposes to those for which they are employed at the present time. A mixture of lead and tin was also used as a solder.

Iron was known in very early times, but in comparatively small quantities, being obtained from meteoric stones, or easily reducible oxides. Moses speaks of iron being used for swords, knives, axes, etc., which seems to imply that steel was known at that early period. Homer represents warriors as armed with bronze swords, and never as using iron weapons. Achilles proposes a ball of iron as a valuable prize to be contended for in the games, which shows its scarcity at that period. That the Romans were acquainted with steel, as well as with the method of hardening and tempering it, we have abundant evidence. The steel was probably manufactured direct from iron ore. Steel may be considered as an alloy of iron and carbon, into which manganese occasionally enters in small proportion.

Thus the ancients knew the six malleable metals and their alloys above referred to, but they have left us scant information respecting the methods of extracting them from the ores. It is probable that only those ores of a simple character, or those readily acted upon by reducing agents, were employed, unless the appliances at their disposal and their general chemical knowledge were superior to what known facts warrant us in believing.

In the eighteenth century the investigation of the nature of alloys began to receive systematic scientific attention. Thus Reaumur, an indefatigable French chemist, concluded that steel was iron impregnated with sulphurous and saline matters. The word "sulphurous" as used at that time is nearly synonymous with the present term "combustible." At the end of that century, Berthollet concluded from his own experiments and those of Reaumur that steel was a compound of iron and carbon. Reaumur also explained the principle of the method of tinning iron plates. Gellert in his *Metallurgic Chemistry* endeavours to point out the analogy between alloys and solutions, and gives a table showing the relative solubilities of metals in each other, such as copper in silver. He further clearly showed that with regard to the solution of metals in a triple alloy, he understood the possibility of the division of a metal between two metals acting as solvents. Musschenbroek in the early part of the eighteenth century made some experiments on the tensile strength of metals and alloys. He writes of the "absolute cohesion by which a body resists fracture when acted on by force-drawing according to its length." Duhamel in 1792 writes of the necessity for making exact experiments upon alloys, with metals which possess a high degree of purity, the union being effected in closed vessels.

In the early part of the nineteenth century the researches on alloys became more numerous, and the interest excited in them has continued to grow to the present day.

NATURE OF METALS

§ 2. The term "metal" indicates a certain number of the chemical elements which have well-defined characters in common, such as metallic lustre, conductivity, and high specific gravity. When separated from their compounds by electrolytic action they appear at the negative electrode, and hence belong to the class of electro-positive bodies. These properties are by no means equally developed in all cases; in some instances one or more of these characteristics may be absent. On the other hand, there are substances not metallic in character in which some of these properties are strongly displayed. Thus, graphite has a metallic lustre, gas-carbon and silicon are conductors of heat and electricity, and the alkali metals are lighter than water. In fact, while there are elements having strongly marked characteristics, which may unhesitatingly be classed as metallic, there are others, such as arsenic, which have properties either metallic or non-metallic according to the standpoint from which they are viewed. These bodies form a connecting link between metals and non-metals, making it impossible to draw a strict line of demarcation.

The influence of heat upon metals is very varied; some melt at a low temperature, others require a red heat, a strong red, or a white heat respectively, to melt them. The following table by Pouillet will explain the temperatures corresponding to different colours:—

Incipient red heat	corresponds to	525° C.	977° F.
Dull red	,,	700	1292
Incipient cherry red	,,	800	1472
Cherry red	,,	900	1652
Clear cherry red	,,	1000	1832
Deep orange	,,	1100	2012
Clear orange	,,	1200	2192
White	,,	1300	2372
Bright white	,,	1400	2552
Dazzling white	,,	1500	2732

Metals expand when heated and contract on cooling, and, within certain limits, the expansion is proportional to the degree of heat. Certain anomalies, however, exist, thus: molten cast-iron expands at the moment of becoming solid, and solidified bismuth occupies a larger space than bismuth in the liquid state. One of the most distinctive features of a metal is an internal mobility, in virtue of which its shape may be altered by pressure without disruption of the mass. This property is possessed by metals in various degrees, so that the "malleability" or capability of being extended by pressure without cracking, and "ductility," or the capability of being permanently elongated by a tensile stress combined with lateral pressure, are by no means equal in extent; nor is the order of their malleability the same as for ductility, for the former depends on the softness and tenacity, while the latter is much more dependent on tenacity.

By "tenacity" or tensile strength is understood the resistance a body offers to an attempt to pull its particles asunder when a stretching force is applied. The tenacity is generally diminished by a rise in temperature, while the reverse is often the case with regard to malleability and ductility. Some metals have a feeble tenacity, and are then said to be brittle. When a body resists rupture by a bending or twisting force, it is said to be "tough." Elasticity is a property of bodies, in virtue of which they tend to recover their size and shape after being subjected to a disturbing force. There is a limit in every solid body, beyond which it will not return to its original form on the withdrawal of the force; this is termed *the limit of perfect elasticity.* "Hardness," which is measured by resistance to a compressive force, like all the other physical properties of a metal, is modified by the presence of impurities, so that, in many cases, softness is a test of purity. All malleable metals become hardened by pressure, and often require annealing during the process of manufacture. The fractured surface of metals is often characteristic, being spoken of as fibrous, crystalline, granular, columnar, and conchoidal, thus: wrought-iron is fibrous, zinc is crystalline, steel is granular, tin is columnar, and hard steel is conchoidal. Crystalline structure is often accompanied by brittleness, and fibrous structure by high tenacity. Most metals are much heavier than water, and the ratio which expresses the number of times a body is heavier than an equal volume of water is termed its "specific gravity." The "specific heat" or the capacity of a body for heat extends over a wide range with regard to metals; iron, for example, being $\frac{1}{10}$ that of water, while lead is less than $\frac{1}{30}$. The oxides of metals are usually basic in character, but this property is only relative, as an oxide which is basic in one compound may become acid when allied with a stronger base.

CLASSIFICATION OF METALS

§ 3. Metals may be more conveniently studied by classify-ing them into groups, according as they approximate in general characters, based chiefly on their affinities for oxygen.

1. **Noble Metals.**—Gold, Platinum, Silver, and a few rare metals. The members of this class have little or no tendency to unite with oxygen in the free state, and when placed in water at a red heat do not alter its composition. The oxides are readily decomposed by heat in consequence of the feeble affinity between the metal and oxygen.

2. **Copper Group.**—Copper, Mercury, Lead, and Bismuth. They do not decompose water, even at a red heat, but unite with oxygen when heated, forming oxides of a basic character. Mercury has the least affinity for oxygen, and in this respect approaches the noble metals in character.

3. **Tin Group.**—Tin, Antimony, Arsenic, etc. These metals, except arsenic, decompose steam at a red heat, and form some oxides of an acid character; in this respect resembling the non-metals. Protoxide of tin is a strong base.

4. **Iron Group.**—Iron, Chromium, Manganese, Nickel, and Cobalt. Steam is decomposed when brought in contact with the members of this group at a red heat. The protoxides form powerful bases. Some of the higher oxides of iron, chromium, and manganese form what may be termed metallic acids, which combine with bases to form salts, soluble in water.

5. **Zinc Group.**—Zinc, Cadmium, and Magnesium. The members of this group oxidise slowly in moist air, but rapidly when heated. They are readily volatile, and burn in air with a bright light, producing oxides, which form powerful bases. At a red heat they decompose steam.

6. **Aluminium Group.**—Aluminium and allied rare metals. Aluminium does not oxidise in air or decompose water, unless the metal is in a very finely divided state. It forms an oxide, which is acid or basic according as it is allied with a stronger or weaker base.

7. **Alkaline-earthy Metals.**—Barium, Strontium, and

Calcium. These metals rapidly decompose water, forming oxides. All the oxides are strongly basic, and readily unite with acids.

8. **Alkali Metals.**—Sodium, Potassium, and Lithium. These metals have such an intense affinity for oxygen that they require to be preserved in some liquid free from that element. The oxides dissolve in water forming powerfully caustic solutions.

NATURE OF NON-METALS

§ 4. All the chemical elements devoid of that combination of physical and chemical properties which constitute the metals are termed non-metals. Only a few of them are found in nature in the free state; namely, oxygen, nitrogen, sulphur, and sometimes carbon and selenium. As a general rule they are opposite to the metals in their electrical relations, being electro-negative, and, consequently, appearing at the positive electrode when their compounds are decomposed by the electric current. The positive or negative character, however, like that of the metals, is not absolute, except in the elements oxygen and fluorine, but varies according to the kind of elements existing in combination. Thus, in the compound known as hydrochloric acid, chlorine is negative; but when chlorine is in combination with oxygen it plays the part of a positive element.

The combination of a metal with a non-metal, such as oxygen, is characterised by a much more decisive change of properties than in the case of union between two metals. The affinity of the different metals for oxygen, sulphur, etc., is however very varied, being more intense the wider the difference between the electrical relations of the constituents. In the case of gold the affinities are so feeble that this metal does not unite directly with either of these non-metals. The compounds of most metals with oxygen form a class of bodies termed bases; while the combination of non-metals with oxygen generally forms a class of bodies of opposite properties, termed acids. Those metals, however, which exhibit the metallic character in a feeble degree, more often have acid than basic properties when combined with oxygen. It is upon these chemical relations, taken in conjunction with the physical properties, that a true classification of the elements into metals and non-metals is based.

CHEMICAL PRINCIPLES AND CHANGES

§ 5. Chemists have found that all bodies, whether in the form of a solid, a liquid, or a gas, are either simple substances or can be resolved into simple substances, termed "elements." These elements are represented by symbols, which are usually the initial letter or letters of their names. Different elements combine together in definite proportions, forming an endless variety of substances termed "compounds."

Elements are classified into "metals" and "non-metals," the former being distinguished by well-marked properties, which are absent in the latter. The ultimate particles or "atoms" which compose any element differ in weight from the atoms of any other element, and the relative weight compared with hydrogen is termed the "atomic weight." The following table gives the chemical elements with their symbols, atomic weights, and specific gravities:—

METALS

Names.	Symbols.	Atomic weights.	Specific gravity.
Aluminium . . .	Al	27·4	2·67
Antimony	Sb	122	6·72
Arsenic	As	75	4·71
Barium	Ba	137	4
Bismuth	Bi	210	9·9
Cadmium	Cd	112	8·6
Caesium	Cs	133	...

METALS—*Continued*

Names.	Symbols.	Atomic weights.	Specific gravity.
Calcium	Ca	40	1·58
Cerium	Ce	92·2	5·5
Chromium	Cr	52·1	6·8
Cobalt	Co	58·8	8·9
Copper	Cu	63·1	8·96
Didymium	Di	95	...
Erbium	E	112·6	...
Glucinum	Gl	9·3	2·1
Gold	Au	196·8	19·5
Indium	In	113·4	7·4
Iridium	Ir	196·9	22·4
Iron	Fe	56	7·84
Lanthanium	La	92·9	...
Lead	Pb	207	11·45
Lithium	Li	7	·58
Magnesium	Mg	24	1·74
Manganese	Mn	55	8
Mercury	Hg	200	13·59
Molybdenum	Mo	96	8·6
Nickel	Ni	58·8	8·9
Niobium	Nb	94	6·67–7·37
Osmium	Os	199·1	21·35
Palladium	Pd	106·6	11·8
Platinum	Pt	197·4	21·5
Potassium	K	39·1	·86
Rhodium	Rh	104·2	11·2
Rubidium	Rb	85·4	1·52
Ruthenium	Ru	104·4	11·4
Silver	Ag	108	10·5
Sodium	Na	23	·98
Strontium	Sr	87·5	2·58
Tantalum	Ta	182·3	10·78
Thallium	Tl	203·5	11·9
Thorium	Th	115·7	...
Tin	Sn	118	7·3
Titanium	Ti	50	...
Tungsten	W	184	19·26
Uranium	U	237·6	18·4
Vanadium	V	51·3	5·5
Yttrium	Y	61·7	...
Zinc	Zn	65·2	7·11
Zirconium	Zr	89·6	4·15

NON-METALS

Names.		Symbols.	Atomic weights.	Specific gravity.
Boron		B	11	2·68
Bromine		Br	80	2·96
Carbon	Graphite	...	...	2·2
		C	12	...
	Diamond	...	...	3·5
Chlorine		Cl	35·5	...
Fluorine		F	19	...
Hydrogen ?		H	1	...
Iodine		I	127	4·95
Nitrogen		N	14	...
Oxygen		O	16	...
Phosphorus		P	31	1·8–2·1
Selenium		Se	79·5	4·28–4·8
Silicon		Si	28·1	2·49
Sulphur		S	32	1·97–2·07
Tellurium		Te	128	6·18

Compounds are formed, as already stated, by the combination of different elements, thus : FeO represents oxide of iron, and MnO oxide of manganese. In many cases two elements unite in more than one proportion, such as FeO, Fe_2O_3, Fe_3O_4, each of which requires a distinguishing name. There are several systems of nomenclature, but the simplest—for compounds containing two elements—is that of writing the name of the metal first, and the non-metal or least metallic element afterwards, giving it the termination "ide." When two non-metals combine, the one which is most unlike a metal is written second. Sometimes Greek prefixes are used for the element of the second position, such as *mono*, *di*, *tri*, *tetr*, etc., to indicate the number of atoms present. Another system is to make the metal terminate in "ic" or "ous." That compound which contains the greater proportion of the non-metallic constituent is distinguished by the suffix "ic" and that containing the smaller by the termination "ous." The following list will illustrate these points :—

Name.	Name.	Name.	Formula.
Iron oxide	Ferrous oxide	Iron protoxide	FeO
Iron trioxide	Ferric oxide	Iron sesquioxide	Fe_2O_3
Iron tetroxide	Triferric tetroxide	Black oxide of iron	Fe_3O_4
Manganese oxide	Manganous oxide	Manganese protoxide	MnO
Manganese dioxide	Manganic oxide	Manganese peroxide	MnO_2
Aluminium oxide	Aluminic oxide	Alumina	Al_2O_3
Calcium oxide	Calcic oxide	Lime	CaO
Magnesium oxide	Magnesic oxide	Magnesia	MgO
Titanium dioxide	——	Titanic acid	TiO_2
Carbon monoxide	Carbonic oxide	——	CO
Carbon dioxide	——	Carbonic acid	CO_2
Silicon dioxide	Silicic oxide	Silica	SiO_2
Phosphorus pentoxide	Phosphoric oxide	Phosphoric acid	P_2O_5
Sulphur dioxide	Sulphurous oxide	Sulphurous acid	SO_2
Sulphur trioxide	Sulphuric oxide	Sulphuric acid	SO_3

When three elements—one being a metal and another oxygen—are combined together, the name of the second is made to end in "ate." In the following list a few compounds are given to illustrate this, but it should be observed that the order of placing the symbols is immaterial. In works on metallurgy the arrangement of formulæ in the last column is most common.

Name.	Name.	Formulæ.
Iron silicate	Ferrous silicate	$FeSiO_3$ or $FeO.SiO_2$
,, ,,	,, ,,	Fe_2SiO_4 or $2FeO.SiO_2$
Iron sulphate	Ferrous sulphate	$FeSO_4$ or $FeO.SO_3$
Calcium silicate	Silicate of lime	$CaSiO_3$ or $CaO.SiO_2$
Aluminium silicate	Silicate of alumina	$Al_4Si_3O_{12}$or$2Al_2O_3.3SiO_2$
Calcium carbonate	Carbonate of lime (Limestone)	$CaCO_3$ or $CaO.CO_2$
Copper carbonate	Cupric carbonate	$CuCO_3$ or $CuO.CO_2$

Equations.—When two or more elements unite to form a compound, or two compounds unite to form a more complex compound, the change may be represented by a chemical equation, thus :—

$$\begin{array}{ccccc} 3\mathrm{Fe} & + & 4\mathrm{O} & = & \mathrm{Fe_3O_4} \\ \text{Iron.} & & \text{Oxygen.} & & \text{Iron tetroxide.} \\ 3 \times 56 & & 4 \times 16 & & 168 + 64 \end{array}$$

$$\begin{array}{ccccc} \mathrm{FeO} & + & \mathrm{SiO_2} & = & \mathrm{FeO.SiO_2} \\ \text{Ferrous oxide.} & & \text{Silica.} & & \text{Ferrous silicate.} \\ 56 + 16 & & 28 + 32 & & 72 + 60 \end{array}$$

Any chemical change may be so represented, the bodies taking part in the change being placed on the left-hand side of the sign of equality "=," and the bodies formed after the change, on the right-hand side.

The quantities involved in any such change can be seen at a glance, since the symbol of an element represents a definite weight, given in the table, pp. 9-11, as the atomic weight. Thus, in the first equation 3×56 parts of iron unite with 4×16 parts of oxygen to form $168 + 64 = 232$ parts of the black oxide of iron.

When a chemical change occurs, the production or absorption of heat is the result, the former by the union of elements or compounds, the latter by the forcible separation of the constituents of a compound. When the temperature produced is considerable, it is usual to speak of it as combustion; thus, carbon combines with oxygen to produce carbonic acid and generates intense heat.

$$\begin{array}{ccccc} \mathrm{C} & + & 2\mathrm{O} & = & \mathrm{CO_2} \\ \text{Carbon.} & & \text{Oxygen.} & & \text{Carbonic acid.} \end{array}$$

In common language it is said to burn, and the burning of fuel is simply the result of chemical combination.

When substances combine with oxygen they are said to be "oxidised," and the substance which imparts the oxygen is termed an oxidising agent. Conversely, substances which remove oxygen from a body are termed reducing agents. The following lists give some examples of both kinds :—

Oxidising Agents.

- Oxygen (O).
- Air (O and N).
- Iron tetroxide (Fe_3O_4).
- Manganese dioxide MnO_2.
- Slags containing the above or similar oxides.
- Carbonic acid (CO_2).
- Water (H_2O).

Reducing Agents.

- Carbon (C).
- Carbonic oxide (CO).
- Hydrogen (H).
- Compounds of carbon and hydrogen, such as coal-gas.
- All fuels.
- Sometimes metals.

Examples of Oxidation.

$3PbO$	+	O	=	Pb_3O_4		
Lead oxide.		Oxygen.		Red lead.		
$3FeCO_3$	+	O	=	Fe_3O_4	+	$3CO_2$
Iron carbonate.		Oxygen.		Iron tetroxide.		Carbonic acid.
$3FeO$	+	CO_2	=	Fe_3O_4	+	CO
Iron oxide.		Carbonic acid.		Iron tetroxide.		Carbonic oxide.

Examples of Reduction.

$2PbO$	+	C	=	CO_2	+	Pb_2
Lead oxide.		Carbon.		Carbonic acid.		Lead.
Fe_2O_3	+	$6H$	=	$2Fe$	+	$3H_2O$
Ferric oxide.		Hydrogen.		Iron.		Water.
ZnO	+	CO	=	Zn	+	CO_2
Zinc oxide.		Carbonic oxide.		Zinc.		Carbonic acid.
Fe_2O_3	+	CO	=	$2FeO$	+	CO_2
Ferric oxide.		Carbonic oxide.		Ferrous oxide.		Carbonic acid.
PbS	+	Fe	=	Pb	+	FeS
Lead sulphide.		Iron.		Lead.		Ferrous sulphide.

It will be obvious that in the cases of oxidation and reduction, the change may be partial or complete. Thus, iron is completely oxidised when converted into Fe_2O_3, and oxide of iron is completely reduced when all the iron is brought to the metallic state.

The following is a short description of the chief non-metals mentioned in the present section, and which are subsequently alluded to.

Oxygen (O).—This is the most abundant element, forming probably one-half the solid crust of the earth, $\frac{8}{9}$ of all water, and about 21 per cent by volume of the air. It is necessary for life and all ordinary processes of combustion. In the air it is a gas, but its compounds are chiefly solid or liquid. Its oxidising action has been already mentioned. It is the chief supporter of combustion, that is, it forms the active medium in which bodies burn.

Oxides, as the compounds of oxygen with other elements are termed, may be roughly divided into two groups. 1°. Those which have an acid character, chiefly oxides of the non-metals, and often termed acids, such as carbonic acid CO_2, and silica SiO_2. 2°. Those of a basic character, chiefly oxides of the metals, which are termed bases. These two classes are opposite in character, and when united in equivalent proportions, generally neutralise each other, forming what are termed "neutral" bodies, which do not possess the characteristic properties of either kind. Thus silica SiO_2 will neutralise oxide of iron FeO, forming a silicate, which is neither acid nor basic. If any compound contain an excess of acid or base, it is classified either as an acid or as a basic substance, according to the kind which predominates. Thus, $3FeO.SiO_2$ is a basic silicate, and $FeO.SiO_2$ an acid silicate, because in the former there is more FeO than is required to neutralise the acid SiO_2, and in the latter less than is necessary for this purpose.

Hydrogen (H) is chiefly found in nature in combination with oxygen, forming water H_2O, which contains $\frac{1}{9}$ its weight of hydrogen. It differs from other non-metals in not generally uniting with metals to form compounds, but metals such as palladium and iron absorb it in large quantities, when it is said to be occluded. It burns in air or in pure oxygen, forming water, and evolving great heat—

$$2H + O = H_2O.$$

It is a constituent of wood, peat, coal, and coal-gas, part of it probably existing in these bodies as water; and in combination with carbon it forms what are termed hydrocarbons, such as marsh-gas CH_4, and olefiant-gas C_2H_4. When the latter are burnt the hydrogen forms water, thus—

$$\underset{\text{Marsh-gas.}}{CH_4} + \underset{\text{Oxygen.}}{4O} = \underset{\text{Carbonic acid.}}{CO_2} + \underset{\text{Water.}}{2H_2O}$$

$$\underset{\text{Olefiant-gas.}}{C_2H_4} + \underset{\text{Oxygen.}}{6O} = \underset{\text{Carbonic acid.}}{2CO_2} + \underset{\text{Water.}}{2H_2O}$$

In some furnaces and gas-producers, steam is introduced along with air to increase the volume of combustible gases, but only a very limited amount of steam can be used for this purpose.

Nitrogen (N) forms about 79 per cent by volume of the air, its chief function being to modify the active properties of oxygen. It neither burns nor supports combustion, so that the nitrogen which enters a furnace, for the most part, comes out unchanged, thus robbing it of a large amount of heat, without contributing any itself.

Air is simply a mixture of oxygen and nitrogen along with small quantities of water and carbonic acid. Omitting the latter, its composition may be taken as—

	By Volume.		By Weight.
N	79	N	77
O	21	O	23
	100		100

A ton of air thus contains about 515 lbs. of oxygen. Air resembles oxygen in its properties, but is less active on account of the inactive nitrogen.

Silicon (Si).—This non-metal is a grayish-black substance. It is generally present in iron and a few other metals, and supposed to exist, like carbon, in the "free" and in the "combined" state. It is of little importance as an element, but in combination it forms about ¼ of the earth's crust. It burns in oxygen, forming silica, thus—

$$\underset{\text{Silicon.}}{Si} + \underset{\text{Oxygen.}}{2O} = \underset{\text{Silica.}}{SiO_2}$$

Silica (SiO_2) plays a prominent part in the reduction of metals from their ores, being the chief slag-forming substance. It exists largely as sand, and in combination with "bases" it forms silicates. The various slags are chiefly combinations of SiO_2 with alumina Al_2O_3, lime CaO, and other metallic oxides which fuse at high temperatures. Uncombined silica is practically infusible.

Carbon (C).—This non-metal is an essential constituent of all living matter, and of all ordinary fuels, such as coal. It exists in the free state as the diamond, and as graphite or black-lead. In the latter form it is used in the manufacture of crucibles, etc., because of its infusibility, and its non-tendency to form fusible slags with acid or basic substances. It will burn away in contact with air, but will not melt or vaporise. It exists in pig-iron and steel in the free and in the combined state. Part of the free carbon of pig-iron sometimes rises to the surface of the molten mass when allowed to stand, and is known as "kish." Charcoal and coke are almost entirely composed of carbon, with a little earthy matter, which is left as ash when the carbon is burnt. Either form of carbon will burn in oxygen, forming oxides. When carbon is strongly heated in the presence of steam the latter is decomposed and the carbon oxidised thus—

$$\underset{\text{Carbon.}}{C} + \underset{\text{Water.}}{H_2O} = \underset{\text{Hydrogen.}}{H_2} + \underset{\text{Carbonic oxide.}}{CO}$$

$$\underset{\text{Carbon.}}{3C} + \underset{\text{Water.}}{2H_2O} = \underset{\text{Marsh-gas.}}{CH_4} + \underset{\text{Carbonic oxide.}}{2CO}$$

Carbon dioxide or Carbonic acid (CO_2) is a gas about 1½ times the weight of air, and is formed when carbon is burned in oxygen or in a free supply of air, thus—

$$\underset{\text{Carbon.}}{C} + \underset{\text{Oxygen.}}{2O} = \underset{\text{Carbonic acid.}}{CO_2}$$

Also when carbonic oxide is burned in air or oxygen, thus—

$$\underset{\text{Carbonic oxide.}}{CO} + \underset{\text{Oxygen.}}{O} = \underset{\text{Carbonic acid.}}{CO_2}$$

If carbon dioxide is brought in contact with red-hot carbon, it takes up some of the latter, forming twice its volume of carbonic oxide (CO), thus—

$$\underset{\text{Carbonic acid.}}{CO_2} + \underset{\text{Carbon.}}{C} = \underset{\text{Carbonic oxide.}}{2CO.}$$

In this case carbonic acid is oxidising. CO_2 is not poisonous, but it will not support life or ordinary combustion.

Carbon monoxide or Carbonic oxide (CO) is a colourless gas, about the same weight as air, extremely poisonous, and burns in air or oxygen with a blue flame producing carbonic acid, and evolving considerable heat. The combustible gas formed in gas-producers is chiefly carbonic oxide. It is a powerful reducing agent, probably the chief agent in reducing oxide of iron in the blast-furnace, and zinc oxide in zinc muffles. At high temperatures CO is decomposed, especially in the presence of other bodies, such as iron, which combine with carbon.

$$\underset{\text{Carbonic oxide.}}{2CO} = \underset{\text{Carbon.}}{C} + \underset{\text{Carbonic acid.}}{CO_2}$$

This is probably the case in the blast-furnace, and in the cementation process for steel.

Phosphorus (P).—This non-metal is generally a waxy-looking crystalline solid, which readily melts and vaporises. It is highly inflammable in air, forming a white cloud of phosphorus pentoxide P_2O_5, also called phosphoric acid. It combines with oxygen in two proportions, forming oxides of phosphorus. One of these oxides unites with bases to form compounds termed phosphates. It probably exists in metals as an element, but in slags as a phosphate. Thus, in refining pig-iron, phosphate of iron ($3FeO.P_2O_5$) is found in tap-cinder, and phosphate of lime ($4CaO.P_2O_5$) in basic slag.

Phosphates are decomposed by silica at high temperatures, because under these conditions SiO_2 is non-volatile, thus—

$$\underset{\text{Iron phosphate.}}{3FeO.P_2O_5} + \underset{\text{Silica.}}{SiO_2} = \underset{\text{Iron silicate.}}{3FeO.SiO_2} + \underset{\text{Phosphoric acid.}}{P_2O_5}$$

Phosphoric acid is reduced by carbon, or even by iron, the phosphorus uniting with the iron, thus—

$$\underset{\text{Phosphoric acid.}}{P_2O_5} + \underset{\text{Carbon.}}{5C} = \underset{\text{Carbonic oxide.}}{5CO} + \underset{\text{Phosphorus.}}{2P}$$

Sulphur (S) is a non-metal, and solid at ordinary temperatures. It readily melts and vaporises, and unites with metals forming sulphides, such as ferrous sulphide FeS. With oxygen it forms oxides, viz. sulphur dioxide SO_2, and sulphur trioxide SO_3.

Chlorine.—This element exists in nature mainly in combination with sodium, calcium, potassium, magnesium, etc. At ordinary temperatures and pressures chlorine is a greenish-yellow gas, having a pungent and irritating smell, but by great pressure may be liquefied to a dark greenish-yellow liquid, and at low temperatures may be solidified. It is readily soluble in water. It is an active chemical agent, and combines with most metals, forming a class of bodies termed chlorides. Indirectly it acts as a powerful oxidising agent, and is thus used in bleaching and as a disinfectant. In combination with hydrogen it forms hydrochloric acid HCl.

PROPERTIES OF THE METALS

Noble Metals. Gold, Platinum, Silver

§ 6. **Gold** is usually found in the metallic state in nature (generally associated with silver, and sometimes with copper, iron, and platinum). It is often found in ores of lead, zinc, iron, and copper. Gold is a yellow metal, with a brilliant lustre; it exceeds all others with regard to malleability and ductility; its specific gravity is 19·5; its melting point about 1200° C.; and it is only volatile at very high temperatures. It is almost as soft as lead, and can be welded by pressure in the cold; it is one of the best conductors of heat and electricity.

Gold does not oxidise in air, nor is it acted on by any single acid except selenic, but is dissolved by substances like aqua regia which yield chlorine. Chlorine gas unites directly with gold to form chloride of gold $AuCl_3$. It is unacted upon by sulphur or its compounds, so that gold exposed to sulphurous fumes does not become tarnished like silver under similar circumstances. Pure gold is too soft for general use, so that it is usually alloyed with silver and copper, which harden it, without seriously impairing its malleability and ductility. Antimony, arsenic, and lead are most injurious substances in gold, even when present in minute quantities.

Platinum is a white metal, with a brilliant lustre; highly malleable and ductile; as soft as silver, and can readily be welded; it is very tenacious, being only exceeded in this respect by iron and copper among the elementary metals; it only melts at the highest temperatures, such as those of the oxy-hydrogen flame, and the electric arc. It does not oxidise at any temperature, and resists the action of all single acids, its best solvent being aqua regia. It is one of the heaviest metals, having a specific gravity of 21·5. Like silver it absorbs oxygen when melted, giving it out again on cooling, causing the mass to spit. It absorbs considerable quantities of hydrogen and other gases when strongly heated with them, especially the spongy variety called platinum black; if this substance be introduced into a mixture of oxygen and hydrogen it causes them to combine, with the development of great heat.

Platinum occurs in nature, like gold, in the metallic state, in the form of grains or nuggets, and is often associated with iron, copper, gold, silver, and several rare metals.

Silver is remarkable for its whiteness and brilliant lustre, although when precipitated from its solutions it often forms a gray powder; it is harder than gold, but softer than copper, the relative hardness being as 4 : 5 : 7·2. Silver is extremely malleable and ductile, with a tenacity of about 14 tons per square inch; its specific gravity is 10·5, which may be slightly increased by the operations of coining, rolling, hammering, etc.; it melts at about 1000° C.; is one of the best conductors of heat and electricity; is volatile at high temperatures, and at the temperature of the electric arc it may be boiled and distilled. When heated in a current of hydrogen it volatilises at 1330° C. It does not oxidise when heated in air, but molten silver mechanically absorbs oxygen and emits it on solidifying; this is termed "spitting." Silver in a finely divided state is oxidised when heated with certain metallic oxides, such as cupric oxide, manganese dioxide, red lead, etc., these bodies being reduced to lower oxides. Silver is soluble in nitric and sulphuric acids. Silver unites readily with sulphur when heated, forming silver sulphide Ag_2S, which is a dark gray crystalline body, with feeble lustre, somewhat soft and malleable. When heated in air it does not form oxide or sulphate, like most other metallic sulphides, and at a red heat is decomposed into metallic silver and sulphurous acid. Dilute hydrochloric acid has no action on silver sulphide, but the strong acid attacks it. Lead, copper, or iron decompose it when the two bodies are fused together. When silver sulphide is heated with common salt, in the presence of moist air, silver chloride is formed.

Silver and all its salts dissolve in sodium thiosulphate, forming a soluble double thiosulphate ($Na_2S_2O_3 + Ag_2S_2O_3$), when the sodium salt is in excess. Silver combines directly with chlorine to form silver chloride AgCl. The same substance is formed by adding hydrochloric acid, or a solution of common salt to a solution containing silver, when AgCl is precipitated as a white powder; if, however, a large excess of strong salt solution be used the AgCl is dissolved, a double salt being formed thus—

$$AgNO_3 + NaCl = AgCl + NaNO_3$$
$$AgCl + NaCl = (AgCl, NaCl).$$

Silver chloride fuses at a low red heat to a yellow liquid and readily volatilises at a strong red heat. It is insoluble in acids, but soluble in ammonia, sodium chloride, sodium thiosulphate, and potassium cyanide. It may be reduced by hydrogen, carbonate of soda, zinc, iron, and several other metals, and partially by sulphur. It unites with oxide of lead in all proportions, and partially so with sulphide of lead and some other sulphides.

Silver occurs in nature in the metallic state; as sulphide in silver glance, which is often associated with the sulphides of lead, antimony, and iron; as bromide and iodide; as chloride in horn silver; in many lead, zinc, and copper ores; and sometimes in iron pyrites.

Silver is too soft to be worked by itself for most purposes, pure silver being only used in special cases, where the presence of another metal would exert an injurious effect. In most cases, silver is alloyed with copper, and occasionally with other metals, as in silver solders.

COPPER GROUP. COPPER, MERCURY, LEAD, AND BISMUTH

§ 7. **Copper** has a red colour; is highly malleable, ductile, tough, and tenacious; it melts at about 1100° C., is not sensibly volatile, except at very high temperatures; its specific gravity is 8·96, which may be slightly increased by hammering and rolling. Copper is one of the best conductors of heat and electricity, but this property is considerably interfered with by the presence of small traces of impurities. When a bar of pure copper is freshly broken it exhibits a fibrous silky fracture, of a light salmon colour. It readily unites with oxygen at a red heat, forming one or both of the two oxides, known respectively as black and red oxide, in virtue of their colour. The red or cuprous oxide is highly basic, and unites with acid substances, such as silica, forming copper salts. Cuprous oxide is soluble in molten copper, making it dry in appearance and brittle in character.

This may be remedied by remelting the copper with a little charcoal, and stirring with a pole of green wood. Commercial or tough-pitch copper is never pure, but the impurities are neutralised by the presence of a little oxygen. If the poling referred to above be continued too far, the neutralising oxygen is removed and the other impurities present act on the copper prejudicially, making it brittle. The copper is then said to be over-poled.

Copper unites directly with sulphur when the two bodies are heated together forming cuprous sulphide, which is of a dark bluish-gray colour, shows a finely-granular fractured surface when broken, and has a metallic lustre.

Phosphorus is highly injurious to copper when allowed to remain in it, but a small quantity may, under certain circumstances, exert a refining influence, provided the whole of it is afterwards removed.

The element silicon, when reduced from sand by the action of carbon, unites with copper, making it much harder, and causing it somewhat to resemble gun-metal in colour, but diminishes its toughness and malleability.

Lead, arsenic, and antimony have a very injurious action on copper, making it hard, brittle, and cold-short.

The common impurities in copper are iron, arsenic, antimony, and cuprous oxide; sometimes tin, bismuth, sulphur, lead, nickel, and cobalt are present. The varieties of commercial copper are:—rosette or Japan copper, the surface of which presents a peculiar red colour, due to a coating of oxide, formed by throwing water on the surface of the metal while in a heated state. Bean-shot and feathered-shot copper, which are obtained in the form of globules and flakes respectively, by running the metal into hot or cold water. Tough-cake is a variety cast into rectangular slabs, convenient for rolling, etc. Best-selected is the name applied to the purest variety of commercial copper, special care being taken to free it from sulphur, arsenic, antimony, and iron. Russian-copper, which generally contains traces of iron, but is otherwise very pure. Chili-bars. This variety, as imported into this country, is prepared in bars weighing about 200 lbs. each; the copper being in a raw state, requires to be refined before it is ready for use.

Mercury.—This is the only one of the useful metals which is liquid at ordinary temperatures; it is also called quicksilver, and has been known from the most remote times. It has a silver-white colour with a brilliant lustre; is devoid of taste or odour when pure; at a temperature of 360° it boils, and at 39·4° C. it solidifies, forming a soft, white, malleable mass, exhibiting a granular structure on the freshly fractured surface. It has a high and fairly regular coefficient of expansion for heat, which renders it suitable for thermometers and similar instruments; its specific heat is ·0332, and its density at 4° C. is 13·59. Liquid mercury does not oxidise in air, except when near its boiling point, which forms a ready means of detecting the presence of base metals, such as lead and antimony, added as adulterations, or present as impurities. Impure mercury, when exposed to air or oxygen, becomes coated with a gray film, due to the oxidation of the impurities. At its boiling point mercury is slowly oxidised to mercuric oxide HgO. It combines directly with sulphur, forming an important compound, mercuric sulphide or vermilion HgS.

Mercury unites with most metals forming "amalgams," some of which are liquid, others semi-liquid, and some solid. The solid amalgams are regarded as chemical compounds, while the liquid amalgams may be solutions of compounds in excess of mercury, but the affinity is feeble, as the mercury is partially expelled by pressure, and completely so, in most cases, by heat. Amalgams are formed—(1) by rubbing the metal in a finely divided state with mercury, an increase of temperature facilitating the amalgamation; (2) by dipping a metal into the solution of a mercury salt; (3) by voltaic action, as when a metal is placed in contact with mercury and an acid; (4) by mixing a metal, such as gold, with an amalgam of a highly positive metal, such as sodium.

Mercury sometimes occurs in the metallic state, sometimes as an amalgam with silver, and occasionally as chloride, bromide, and iodide of mercury. The chief source of the metal is the sulphide HgS, known as cinnabar.

Lead.—This metal has a bluish-gray colour, and possesses considerable lustre; it is malleable, ductile, and tough, but has a feeble tenacity. The lustre of a freshly cut surface soon becomes dim when exposed to the air, owing to the formation of a film of suboxide of lead. Pure lead emits a dull sound when struck, but the presence of impurities renders it more sonorous; also when the pure metal is cast in the form of a hollow sphere it becomes somewhat sonorous. Its specific gravity is 11·45, and all base metals, when alloyed with it, lower its density. Its melting point is about 330° C., and it is not well adapted for castings, since it contracts considerably on solidifying. It is so soft that it can easily be cut with a knife, and squirted into the form of tubes or rods; two clean surfaces of lead can easily be welded together by pressure in the cold, and also when in a finely divided state, the metal can be pressed into a compact mass. Its specific heat between 0° and 100° C. is ·0314, and its coefficient of expansion is ·00003 for each degree between 0° and 100° C.

If lead is boiled with water containing oxygen it is partially dissolved, and the liquid affords an alkaline reaction. The metal is oxidised when exposed to moist air; it is somewhat volatile when heated in air, forming lead oxide PbO, and this oxide acts as an oxidising agent on many metals, such as copper, zinc, iron, etc. Lead and sulphur unite when heated together, forming lead sulphide PbS, which is a bluish-gray, brittle, and crystalline body.

Commercial lead is often nearly pure, but it generally contains some silver, copper, antimony, tin, and sulphur; and occasionally iron, arsenic, zinc, and manganese.

Bismuth is a hard, grayish-white metal with a reddish tint and bright metallic lustre. Its specific gravity is 9·9, which may be reduced by pressure; it melts at 270° C. and volatilises at a high temperature, burning with a blue flame, forming flowers of bismuth Bi_2O_3; it expands in the act of solidifying. When the metal is melted, and allowed to cool until its surface begins to solidify, the crust broken, and the metal poured out, fine large crystals are obtained. They oxidise in air, and frequently become covered with an iridescent film of oxide. Bismuth unites with sulphur, forming a dark-gray, metallic-looking sulphide Bi_2S_3.

Bismuth serves for the preparation of many pharmaceutical products and cosmetics. The chief use of the metal is in the preparation of fusible alloys, the melting points of which can be altered according to the proportions of their constituents. It occurs in nature in the metallic state, as bismuth-glance Bi_2S_3, as bismuth-ochre Bi_2O_3, and often in company with silver, lead, tin, copper, and cobalt ores.

TIN GROUP. TIN, ANTIMONY, AND ARSENIC

§ 8. **Tin** is a white metal with a brilliant lustre; very malleable, as seen by the thinness to which tin-foil can be reduced. A bar of tin when bent produces a crackling sound, known as the "cry of tin," supposed to be due to the grinding action of its crystals over each other. Its specific gravity is 7·3, it melts at 230° C., and may be somewhat strongly heated without volatilising. When raised to a temperature near its melting point, and allowed to fall from a considerable height, the metal breaks up into the form of long grains, known as grain-tin. When tin is melted, and poured into a mould at a temperature little removed from the point at which it solidifies, the surface remains bright, if pure, but the presence of a little lead, iron, or other base metals imparts a more or less dull and frosted appearance, so that the brilliancy of the surface is a test of purity. Tin is easily crystallised superficially by treating its surface with a mixture of dilute sulphuric and nitric acids; the ornamental appearance, known as *Moirée Metallique*, is obtained in this way. Tin is an inferior conductor of heat and electricity; it takes a high polish, and the radiation of heat from its surface is small. It forms a valuable metal for coating culinary vessels. It is little affected by air at ordinary temperatures, and is therefore used for coating iron to protect it from rust. It unites readily with sulphur on the application of heat, forming stannous sulphide SnS. Commercial tin often contains small portions of lead, iron, copper, arsenic, antimony, bismuth, tungsten, and sometimes manganese and zinc. The tin of commerce is quoted as common, refined, and grain-tin. The refined-tin is made from the best ores, and is more perfectly refined than common tin. Grain-tin is obtained from the best pigs, which are heated and dropped from a height, as referred to on previous page.

The only important ore of tin is tin-stone, which contains tin dioxide SnO_2.

Antimony.—Ordinary commercial antimony is often very impure, containing iron, lead, arsenic, and sulphur, and is called "regulus of antimony." Antimony is a brilliant bluish-white metal, highly crystalline, with fernlike markings on the surface, and very brittle, so that it may be easily powdered; its specific gravity is 6·72; it melts at 450° C., and volatilises at a higher temperature. It does not oxidise at ordinary temperatures, but when heated in air, antimonious oxide Sb_2O_3 is formed; and at a red heat antimony burns with a bluish-white flame producing dense white fumes of Sb_2O_3.

Antimony and sulphur readily unite when heated together, forming Sb_2S_3; the same compound is also formed by heating the oxide with sulphur, thus—

$$2Sb_2O_3 + 9S = 3SO_2 + 2Sb_2S_3.$$

Antimony unites with other metals to form valuable alloys, in consequence of its hardening properties, but it impairs the malleability and ductility of the malleable metals. The effect of even small quantities of antimony on the malleable metals, such as copper, gold, iron, etc., is most injurious, making them hard and brittle.

Antimony occurs native, and in combination with other ores, but the chief ore is "stibnite" Sb_2S_3.

Arsenic.—This metal has a brilliant, dark steel-gray colour, and metallic lustre; it is crystalline, exceedingly brittle, and may be readily reduced to powder. When heated to 180° C. in a closed vessel it begins to volatilise without fusing, and crystallises as it condenses in forms similar to those of antimony. Its vapour is colourless, and possesses a peculiar garlic-like odour. The metal may be exposed to dry air without undergoing change. If heated in air it absorbs oxygen, and burns with a bluish flame, forming arsenious acid As_2O_3, which is condensed as a white powder when in contact with a cool body. The specific gravity of arsenic is 4·71.

Arsenic occurs in nature as realgar As_2S_2, orpiment As_2S_3, mispickel $FeAs+FeS$, nickel pyrites $NiAs$, and kupfer-nickel or copper-nickel $NiAs_2$.

The metal is obtained by heating nickel pyrites, mispickel, etc., in closed retorts, when the arsenic is expelled, and sublimes into condensing chambers.

Arsenic enters into the composition of some alloys, such as shot metal, its general effect being to harden, and render the alloys brittle, and more fusible. Its compounds are used in medicine, and in glass making.

IRON GROUP. IRON, CHROMIUM, MANGANESE, NICKEL, AND COBALT

§ 9. **Iron.**—Malleable iron is of a grayish-white colour, having a granular, crystalline, or fibrous fracture, according to the mode of treatment. When rolled or hammered hot, the iron becomes fibrous, but continued cold hammering induces a crystalline or granular structure, making it hard and brittle. The nature of the fractured surface varies also with the manner in which the iron has been broken, for specimens broken by progressively increasing stresses invariably show a fibrous structure, whilst the same specimen broken by a sudden blow may be crystalline. The presence of impurities generally tends to impart a granular or crystalline fracture, and makes the iron less malleable. When impurities, such as sulphur and arsenic, render the metal unworkable at a red heat, it is said to be hot- or red-short. On the other hand, some substances, such as phosphorus, cause iron to crack when hammered cold; it is then termed cold-short. The specific gravity of iron is about 7·8. Its fusing point is said to be about 2000° C., but before melting it assumes a pasty form, at which point two pieces may be joined together by welding. To ensure a good weld the surfaces must be clean, and the metal at a white heat. In order to dissolve any scale the smith adds a little sand, which unites with the oxide (produced by union of iron with the oxygen of the air), and forms a fusible silicate. The presence of any foreign bodies, such as carbon, silicon, sulphur, phosphorus, copper, oxygen, etc., increases the difficulty of welding. Iron possesses considerable malleability, ductility, and tenacity. Its tensile strength ranges from 17 to 25 tons per square inch, but this, like all the other physical properties, is modified by the presence of impurities, which tend to make it harder, more fusible, and brittle. When iron is heated to dazzling whiteness in air it burns, forming the black oxide Fe_3O_4, the iron becoming friable and brittle, and is then termed "burnt iron." Iron may be magnetised by bringing it in contact with, or near to, a magnet, but soft iron loses its magnetism when the exciting magnet is withdrawn. Its specific heat is ·1137; its conductivity about 120, silver being taken as 1000. Its electric resistance is 5·8 times that of pure copper. When iron is exposed to moist air it readily rusts or oxidises, so that it is often coated with some substance to prevent this action, such as tinning, galvanising, and painting. Professor Barff preserves iron from rusting by exposing it at a red heat to superheated steam, which imparts to it a coating of the black oxide Fe_3O_4.

Pure iron is not a commercial article, but it may be obtained in several ways. 1°. By reducing pure ferric oxide in a porcelain tube by means of a current of hydrogen gas at 700° C.; the iron is obtained in the form of a dark powder, which, when somewhat heated, fires spontaneously in contact with air, forming ferric oxide Fe_2O_3. When the reduction is effected at a much higher temperature, a spongy mass of a silvery gray colour is obtained. 2°. By strongly heating the purest variety of iron wire with a little pure oxide of iron, covering the mixture with powdered glass free from lead, and exposing the whole to a high temperature in a covered clay crucible. The small portion of carbon present in the wire is absorbed in reducing the oxide, while the other impurities pass into the slag. 3°. By electrolytic decomposition of a solution of pure ferrous chloride or sulphate a mass of silvery white, soft, malleable iron is obtained, which, after annealing, has a specific gravity of 7·81.

Iron may be exposed to dry air for an indefinite period without alteration, but in the presence of moisture a layer of rust Fe_2O_3 is formed. The oxidation is accelerated by the presence of carbonic acid, which is always present in the air, a carbonate of iron being formed. This rapidly absorbs a further portion of water and oxygen from the air, and in this way the rusting is slowly conveyed to the centre of the mass of iron. The layer of oxide and carbonate is electro-negative with regard to iron, so that a galvanic action is set up, causing decomposition of the water. This electrical condition still further augments the liability of iron to rust.

When iron is strongly heated in contact with air or oxygen its surface is rapidly coated with a scale of black oxide Fe_3O_4, which peels off when struck with a hammer.

Iron and Sulphur.—Compounds of iron and sulphur occur in nature as pyrites. These elements readily unite when heated together, forming ferrous sulphide FeS. Sulphur, even in small quantities, has a very injurious effect on wrought-iron, making it red-short, although the metal may be readily worked in the cold. With cast-iron a small quantity of sulphur is sometimes an advantage, making it stronger, more fusible, and more liquid when poured. Sulphur in pig-iron tends to the production of the white variety. The surface and fractured portions often exhibit black patches, which are characteristic of sulphur in iron. Ferrous sulphide, heated with carbon, is but little affected, but it is decomposed at a high temperature by oxidising substances. When this sulphide is heated with ferrous sulphate in suitable proportions, the whole of the sulphur is removed as sulphurous acid SO_2, leaving ferric oxide Fe_2O_3.

Iron and Phosphorus.—These bodies readily unite when phosphorus is dropped into red-hot iron, forming a phosphide of iron $Fe_{12}P$. When oxide of iron is reduced in the presence of an earthy phosphate, phosphorus is separated, and unites with the iron. ·3 per cent of phosphorus in wrought-iron makes it harder and somewhat diminishes its tenacity. ·5 per cent makes it cold-short but not red-short. 1 per cent makes it very brittle. The effect of phosphorus on iron is, to impart a coarsely crystalline structure, diminish its strength, increase its fusibility, and make it cold-short. The presence of phosphorus in cast-iron diminishes its strength, but on account of its imparting fluidity to the metal, its presence is beneficial in making fine castings.

Iron and Arsenic.—The effect of arsenic on iron is much the same as that of sulphur, a very small amount will make the metal red-short. Several compounds of iron and arsenic are known, varying from gray to white in colour. Arsenic is not a very frequent impurity in iron.

Iron and Silicon.—A compound of silicon and iron, highly crystalline, and of a silver-white colour, known as silicon iron, is now an article of commerce, and is used for producing soundness in steel castings. It is obtained by reducing silica with carbon in the presence of iron. If iron be heated alone with silica no action takes place. The effect of silicon on cast-iron is to set the combined carbon free, so that, as a rule, the grayer the pig, the higher the amount of silicon present. Silicon makes iron hard, more easily fusible, and brittle.

Iron and Carbon.—Carbon unites with iron in various proportions up to about $4\frac{1}{2}$ per cent, forming the different varieties of steel and cast-iron. When manganese is present a larger proportion of carbon may be taken up. The difference between malleable-iron, steel, and cast-iron is chiefly dependent on the relative amounts of carbon in combination with the iron. The more the carbon, the harder and more fusible the metal becomes, and this effect is considerably increased by the presence of other bodies, such as phosphorus, sulphur, etc. Combination takes place when iron is heated in contact with gaseous fuel, such as carbonic oxide, cyanogen, and hydrocarbons, or by a prolonged exposure to a high temperature in contact with solid carbon, such an operation being termed cementation. When the carbon present in iron reaches ·15 per cent, the iron is sensibly harder; this may be considered the greatest amount of carbon which can be present in malleable iron without diminishing its softness and malleability. Steel may be considered as iron containing from ·15 to 1·8 per cent carbon. When the proportion of carbon is low the metal is termed "mild steel," and in like manner those with the higher proportions of carbon are termed "hard steels." Carbon exists in pig-iron in two states—free and combined. When the carbon is chiefly in the combined form, the iron is "white." On the other hand, when the carbon is free, being diffused through the iron in crystalline scales, the iron is called "gray"; but neither variety is entirely free from graphite or combined carbon respectively. In some varieties the carbon is partly combined and partly free, which gives to the fractured surface of the metal a speckled appearance, consisting of gray spots, enclosed by reticulating lines of white; it is then termed "mottled iron."

Chromium is a comparatively rare metal, which only occurs in nature in combination with other elements, the chief ore being chrome-iron-stone FeO,Cr_2O_3. Chromium, or its oxides, forms the colouring matter of several minerals; the green colour of the emerald, for example, is due to chromium oxide. The metal is obtained by the reduction of its oxide or chloride, or by the electrolysis of its chlorides, when chromium separates out in brittle glistening scales. It is tin-white in colour, having a specific gravity of 6·8. The fused metal is said to be as hard as corundum; it melts with more difficulty than platinum, and is only slowly oxidised when heated in air. It is used in the form of an alloy with iron and carbon, forming a hard, white, and brilliant steel, much esteemed for special purposes.

Manganese.—The pure metal, obtained by the reduction of its oxide, is a gray or reddish-white body, hard, and brittle; its specific gravity is about 8; it oxidises more readily than iron, and must therefore be excluded from air by keeping it under rock-oil, or in sealed vessels. Its chief use is in the formation of alloys with iron, steel, and copper. It is not used in the unalloyed state. Compounds of this metal are very widely distributed in nature; one of the most common is pyrolusite or black oxide of manganese MnO_2.

Nickel.—This is a brilliant-white, malleable, ductile, weldable, and very tenacious metal, with a melting point only a little below that of iron, but the presence of carbon and other impurities considerably lower its fusing point. Its specific gravity is 8·9; it is magnetic like iron, but in a less degree. It does not readily oxidise in air at ordinary temperatures, but when heated the monoxide NiO is formed. It readily unites with sulphur, forming nickel sulphide NiS, which is brass-yellow in colour; and with arsenic, forming nickel arsenide $NiAs$.

Nickel is found in commerce in the form of dull-gray cakes or cubes, and by melting these at a high temperature a compact, silver-white metal is obtained. The malleability of nickel allows of its being fashioned into various articles, which possess great lustre, hardness, and durability. These properties render it valuable for coating base metals by the process of electro-plating, especially as it is little liable to oxidation.

Commercial nickel was formerly very impure, due to the presence of carbon and other bodies, which make it hard and brittle. Dr. Fleitmann and other metallurgists have devised simple and effective means of refining and toughening nickel, which are now largely practised. Fleitmann adds to the melted metal minute quantities of magnesium in several charges, and well stirs each time a dose is added. One ounce of magnesium is sufficient for refining 60 lbs. of impure nickel. The magnesium is supposed to reduce the occluded carbonic oxide CO forming magnesia, and to cause the carbon to separate out as graphite. Nickel unites readily with most metals forming alloys, some of which are of great commercial utility. The most important of these is German silver. Nickel occurs in nature as kupfer-nickel or copper-nickel $NiAs$, which is a copper-red coloured mineral, with a metallic lustre. As nickel pyrites NiS, which is brass-yellow in colour. As nickel-glance, which is a variable compound of nickel, arsenic, and sulphur. As garnierite, which is a hydrated silicate of nickel, iron, and magnesium.

Cobalt.—This metal resembles nickel in appearance and properties, and is generally associated with it in nature. Cobalt is a white metal, highly malleable, ductile, and tenacious; its specific gravity is 8·9; it is magnetic like nickel; almost unalterable in air at ordinary temperatures, but oxidises when heated, and at a high temperature burns with a red flame. It is seldom used in the metallic state, but its compounds are largely employed in pigments. It unites with arsenic to form iron-gray, fusible, and brittle compounds.

The principal ores are smaltine $CoAs$, cobalt glance Co_2AsS, and cobalt bloom $(Co_3AsO_4,4H_2O)$.

ZINC GROUP. ZINC, CADMIUM, AND MAGNESIUM

§ 10. **Zinc**, commonly known by the name of "spelter" when in the cast state, is a white metal, with a bluish shade, and bright metallic lustre. Ordinary zinc is hard and brittle, and when fractured exhibits a highly crystalline structure. When pure it is malleable at the ordinary temperature, while commercial cast-zinc is brittle; the latter, however, becomes malleable and ductile if heated to a temperature of 100° to 150° C., but beyond that point it again becomes brittle. Its specific gravity in the cast state is 6·9, which may be increased to 7·1 by rolling or forging; it contracts but slightly on cooling from the liquid state, and is thus well adapted for castings. The castings made at a high temperature are brittle and crystalline; but when cast near the solidifying point are more malleable. Zinc melts at 412° C. and boils at 1040° C. At a red heat in air it rapidly oxidises, and burns with a greenish-white flame, forming zinc oxide ZnO; if raised to a bright-red heat in a closed vessel, it may be readily distilled. When rolled zinc is exposed to air and moisture a gray film of suboxide is formed, which preserves the metal from further oxidation. Ordinary zinc readily dissolves in dilute hydrochloric and sulphuric acids, while the pure metal is unaffected; both kinds dissolve in nitric acid and in alkalies. Zinc displaces silver, gold, platinum, bismuth, antimony, tin, mercury, and lead from their solutions. The chief impurities of the commercial metal are iron, lead, and arsenic.

Zinc and sulphur do not readily unite, but when a mixture of finely divided zinc and sulphur is projected into a red-hot crucible, some zinc sulphide ZnS is formed. It is also formed by heating zinc with cinnabar HgS.

Zinc forms compounds with phosphorus and arsenic, when these bodies are heated with it, having a metallic lustre and somewhat vitreous fracture.

The chief ores of zinc are:—The oxide ZnO called zincite or red oxide of zinc, which is white when pure, but generally red from the presence of oxide of manganese. The sulphide ZnS, known as "blende" and "black jack," is the principal source of the metal, and generally black or yellowish-black in colour, but sometimes it has a reddish tint from the presence of galena; when pure it is white, and contains 67·03 per cent of zinc. The carbonate $ZnCO_3$, called calamine. And the silicate $(2ZnO,SiO_2,OH_2)$ called electric calamine. Zinc forms with other metals a most important class of alloys, such as brass, German silver, etc. It is used in the form of sheets, worked into a variety of shapes; it protects iron from rusting, as in galvanised-iron; it forms the electro-positive element in many batteries; and in the form of fine dust it is obtained in large quantities mixed with zinc oxide, and forms a valuable reducing agent.

Cadmium.—In the process of zinc extraction it was observed that a volatile vapour, in some cases, was distilled off with the first portions of zinc; this was found to be the metal cadmium. It possesses a tin-white colour, has a fibrous structure, and takes a high polish. It is harder than tin, malleable, ductile, and readily volatile. It has a density of 8·6; it melts at about 320° C., and boils at 860° C. Its vapour is of a dark-yellow colour, with a disagreeable odour. Like tin it emits a crackling sound when bent. It is used in alloys to produce a fusible metal, which melts below 100° C.; and an amalgam of cadmium is employed as a stopping for teeth, such amalgam being soft when first prepared, but soon becomes hard.

Magnesium.—This metal possesses a brilliant-white colour, but soon tarnishes when exposed to moist air, due to the formation of magnesium oxide. It is stated to possess great tensile strength, being nearly equal to that of aluminium bronze. Its specific gravity is 1·74. At a temperature of 450° C. it can be rolled and worked into a variety of forms. Screws and threads made of this metal are sharper and more exact than those made of aluminium. When ignited in a flame it burns with a dazzling white light, which is said to have been seen at sea from a distance of twenty-eight miles. This light is used for purposes of photography. Magnesium occurs abundantly in nature in combination with other elements forming compounds, such as magnesite $MgCO_3$, dolomite $MgCa(CO_3)_2$, etc.

ALUMINIUM

§ 11. **Aluminium.**—With the exception of oxygen and silicon, this is the most widely distributed of the elements, and contained in the largest quantity in the solid crust of the earth. It occurs in a variety of forms as oxide, but more generally in combination with other metals, such as zinc, iron, magnesium, etc., forming aluminates; as silicate in all clays, and as fluoride in cryolite ($6NaF,Al_2F_6$).

Aluminium is a white metal which takes a fine polish. It has no taste or odour. It is soft, very malleable, and ductile, with an elasticity and tenacity about equal to that of silver. Its specific gravity is 2·5, which is increased by hammering; it melts at a temperature a little above that of zinc, and is not volatile when strongly heated out of contact with air. Its conductivity for heat and electricity is said to be very high; but, according to Mr. Roby, it is very low, and diminishes the conductivity of copper considerably when alloyed with it. It does not oxidise in air or combine with sulphur; it is insoluble in cold nitric acid; sulphuric acid has no action on it; but hydrochloric acid and alkalies dissolve it readily.

Aluminium is valuable for making articles where lightness is an important feature; this, combined with its lustre, unalterability in air and sulphuretted hydrogen, non-poisonous properties, and ease of working, gives it a widespread interest. It is, however, in its alloys that its greatest value appears. In some cases it imparts strength, in others it modifies the colour, while in others it promotes soundness in castings.

ALKALINE-EARTHY METALS

§ 12. The term "earth" was formerly used to denote those bodies which are insoluble or but slightly soluble in water, and unaltered by exposure to a high temperature. Some of these were found to have an alkaline reaction, and to easily neutralise acids; hence the term "alkaline earth." These oxides—viz. baryta, strontia, lime, and magnesia—were found to be composed of metals in combination with oxygen.

Barium is a pale yellow metal, malleable, and fusible at a red heat. It rapidly tarnishes in air, and burns brilliantly at a red heat forming barium oxide. Its melting point, according to Frey, is above that of cast-iron. It decomposes water rapidly at the ordinary temperature. Its specific gravity is 4.

Strontium is similar to barium in colour; it is malleable, fusible at a red heat, quickly oxidises on exposure to air, burns brilliantly in air when heated, and violently decomposes water. Its specific gravity is 2·58.

Calcium is a yellow metal, tenacious and malleable; it melts at a red heat, oxidises in air, and burns when heated; it decomposes water rapidly. Its specific gravity is 1·58.

The alkaline-earthy metals, although their compounds are widely distributed, do not occur in nature in the metallic state, and the isolated metals have little application in the arts, on account of their easy oxidation. They may be useful in removing oxygen from other metals and their alloys.

ALKALI METALS. SODIUM, POTASSIUM, LITHIUM, ETC.

§ 13. The word "alkali" was originally used as the name of a soluble salt obtained from the ashes of sea-plants, and is now applied to a well-defined class of bodies having the following properties: They turn red litmus blue, completely neutralise acids, are soluble in water, and their solutions exert a caustic action upon animal matter. The alkalies proper are the oxides of sodium, potassium, lithium, rubidium, and cæsium. To these is added the hypothetical metal ammonium NH_4, which is called the volatile alkali in contradistinction to potash and soda. The metals of the alkalies are soft, readily fusible, volatile bodies, easily oxidised on exposure to air, and they rapidly decompose water at ordinary temperatures.

Sodium.—This metal melts at 96° C. and volatilises forming a dark blue vapour. It rapidly oxidises in air, and when strongly heated burns with a yellow light. It decomposes water rapidly at ordinary temperatures. It is a silver-white metal, with a specific gravity of ·98. Sodium is used for the preparation of aluminium, magnesium, boron, and silicon. As an amalgam it is used in the extraction of gold, and in the laboratory as a reducing agent. It occurs very abundantly in nature in a state of combination; in the forms of chloride, nitrate, borate, carbonate, and silicate.

Potassium.—This element is very similar to sodium in appearance and properties. It is a silver-white lustrous metal, having a specific gravity of ·86; it is brittle at 0° C., but at 15° C. it becomes soft, malleable, and weldable; it melts at 62·5° C., forming a liquid like mercury in appearance; at a red heat it boils, emitting a green-coloured vapour. It has a strong affinity for oxygen, and decomposes water, with evolution of great heat. It is used for similar purposes to those of sodium, and occurs abundantly in nature in analogous forms.

Lithium.—This is a widely diffused element, being found in many micas and felspars, in the ashes of plants, and in sea-water. It has the colour and lustre of silver, is soft and weldable, melts at 180° C., is volatile at a high temperature, burning with a white flame, and rapidly oxidises in contact with air at ordinary temperatures; its specific gravity is ·58, and it is therefore the lightest of all solid and liquid bodies.

Rubidium and Cæsium.—These rare metals so closely resemble potassium that they cannot be distinguished from that metal by many of the ordinary tests. Their presence is detected by means of spectrum analysis.

NATURE OF ALLOYS

§ 14. When two or more metals are caused permanently to unite the resulting mixture is termed an alloy. When mercury is an essential constituent the mixture is then termed an amalgam. The general method of effecting combination is by the agency of heat, but with certain soft metals true alloys may be formed by subjecting the constituents to considerable pressure, even at the ordinary temperature.

Alloys, such as those briefly referred to in the historical sketch, were doubtless first discovered by the metallurgical treatment of mixed ores, from the simultaneous reduction of which, alloys would be formed; or in some cases, as in ores of gold and silver, naturally formed alloys would be obtained by a simple melting process. The direct preparation of alloys by the simple melting together of the constituent metals has been enormously developed in modern times, and the attention which mixed metals are now receiving by chemists is far greater than in any period of history.

Comparatively few of the metals possess properties such as render them suitable to be employed alone by the manufacturer; but most of them have important applications in the form of alloys. Even among the metals which can be used independently, it is often found expedient to add portions of other metals, to improve or otherwise modify their physical properties. Thus gold is hardened, and made to resist wear and tear, as well as to lower its cost, by the addition of copper; silver is likewise hardened by alloying it with copper; and the bronze coinage is formed of an alloy of copper, zinc, and tin for similar reasons.

The purposes for which metals are alloyed are as various as the uses of the metals themselves, but, as a rule, the combination is employed to harden, render more fusible, alter the colour, or to reduce the cost of production. Thus the class of alloys known as solders, which are used for joining the several parts of a body or bodies together, are formed so as to possess melting-points below that of the articles to be soldered. The well-known class of alloys termed "brass" furnishes a good illustration of the effect of alloying in producing different shades of colour. These bodies are composed of the metals copper and zinc in varying proportions, the colour depending to a great extent on the quantity of copper present. When the copper predominates the colour is yellow, or reddish, when the two metals exist in equal proportions the colour is still yellow; beyond this, when the zinc is in excess, the colour gets white, or bluish-white, resembling impure zinc. Nickel is added to brass to whiten it, forming German silver.

Again, some metals, such as copper, can only with difficulty be made to produce sound castings; and the metal is too tough to be conveniently wrought in the lathe or with the file, but when alloyed with zinc or tin, good castings can be readily obtained, and rolled, turned, or filed with considerable facility. In some cases the tensile strength of a metal is enormously increased by the addition of another metal, sometimes in very small proportions; the various bronzes may be cited as examples. The addition of a second metal is often a source of weakness, as in the case of adding antimony to lead. One might be led to consider that the alloying of two malleable metals would produce a malleable alloy, and while in many cases this undoubtedly is so, there are others in which the opposite is the fact. Thus lead added to gold in very small quantity makes the gold exceedingly brittle and weak.

The specific gravity of an alloy nearly always differs from the mean specific gravities of the constituents, sometimes being greater and sometimes less. When the density is increased it shows that contraction has occurred, and chemical combination has probably taken place between the components. This is the case with bronze rich in copper, while with similar alloys rich in tin expansion occurs, the specific gravity being less than the mean of the specific gravities of the two metals. One of the greatest difficulties connected with the subject of alloying is the tendency of the constituents to separate on cooling according to their specific gravities. As a rule, it is more difficult to alloy three or four metals than two metals, especially when the components differ widely in fusibility, unless the combination forms a true chemical compound. The mixture is promoted by constant agitation when the body is in the liquid condition, and by pouring the metal into the mould at the lowest possible temperature consistent with the proper degree of liquidity.

Most metals are capable, to some extent, of existing in a state of chemical combination with each other, but, as a general rule, they are united by feeble affinities, for it is necessary, in order to produce energetic union, that the constituents should exhibit great dissimilarity in properties. It is probable that the metals do unite in definite proportions, but it is difficult to obtain these compounds in a separate condition, since they dissolve in all proportions in the melted metals, and do not generally differ so widely in their melting points from the metals they may be mixed with, as to be separated by crystallisation in a definite condition. For these reasons it has been questioned whether alloys are true chemical compounds. Definite compounds do, however, exist in definite proportions by weight in the native as well as the artificial state. Such is the case with mercury and silver, which are found crystallised together in the proportion of one atom of silver to two or three atoms of mercury. A good illustration of chemical combination between two metals is seen in the alloy of copper and tin, which may be represented by the formula $SnCu_3$, containing 38·4 parts of tin and 61·6 parts of copper. It is distinguished by its peculiar colour, its homogeneity after repeated fusions, its brittleness, and by having a greater density than any other alloy of these metals.

As a general rule, it may be stated that all metals which unite with oxygen to form only bases, have a strong tendency to unite with metals some of whose oxides possess an acid character; and those metals which are allied in regard to basicity or acidity, have little affinity for each other. Thus sodium and potassium, although miscible in various proportions, exhibit little or no tendency to unite in definite quantities; and the same is true of antimony and tin. On the other hand, copper and tin form very stable alloys. In some instances, as in the case of lead and zinc, only very unequal portions can be made to unite, the main bulk of the metals separating on cooling; the lead retaining 1·6 per cent of zinc, and the zinc retaining 1·2 per cent of lead. In all cases of mixed metals there is not that total and complete alteration in properties which is the distinctive feature of chemical action between a metal and a non-metal. Alloys still possess the metallic character, but there is frequently a considerable evolution of heat evinced; the melting points, as in fusible metal, are considerably lowered; the mean density is increased, and the colour and other physical properties are considerably modified. Most often, however, as already indicated, alloys seem to be mixtures of definite compounds with an excess of one or other metal, and the separation of their components from each other is generally easily effected by simple means. Thus an alloy of lead and copper may be largely separated by exposing the mixture to a temperature above that of the fusing point of lead, but below that of copper, when the lead liquates out, leaving behind a porous mass of copper, containing a little lead. Also in remelting brass, a considerable quantity of zinc is lost by volatilisation. When silver is amalgamated with mercury the amalgam is dissolved in an excess of mercury, which excess is removed by simple pressure; and the remaining portion of mercury is completely separated by the agency of heat.

Many metals combine together when melted, and only remain in union within certain ranges of temperature, as shown by the wide differences between their melting and solidifying points. Matthiessen regards it as probable that the condition of an alloy of two metals in the liquid state may be either that of—(1) a solution of one metal in another; (2) chemical combination; (3) mechanical mixture; or (4) a solution or mixture of two or all of the above; and that similar differences may obtain as to its condition in the solid state. He also classifies the solid alloys composed of two metals according to their chemical nature.

1. Solidified solutions of one metal in another: lead-tin, cadmium-tin, zinc-tin, zinc-cadmium, and lead-cadmium alloys.

2. Solidified solutions of one metal in the allotropic modification of another: lead-bismuth, tin-bismuth, tin-copper, zinc-copper, lead-silver, and tin-silver alloys.

3. Solidified solutions of allotropic modifications of the metals in each other: bismuth-gold, bismuth-silver, palladium-silver, platinum-silver, gold-copper, and gold-silver alloys.

4. Chemical compounds of the alloys corresponding to Sn_5Au, Sn_2Au, and Au_2Sn.

5. Solidified solutions of chemical compounds in each other: the alloys intermediate between those corresponding to the above formulæ.

6. Mechanical mixtures of solidified solutions of one metal in another: alloys of lead and zinc containing more than 1·2 per cent of lead, or 1·6 per cent of zinc.

7. Mechanical mixtures of solidified solutions of one metal in the allotropic modification of another: alloys of zinc and bismuth containing more than 14 per cent zinc, or more than 24 per cent bismuth.

8. Mechanical mixtures of solidified solutions of allotropic modifications of the two metals in each other: most of the silver-copper alloys.[1]

As before stated, many mixtures, the components of which may be united in the liquid condition, separate to some extent on cooling. In fact, a cooling mass of mixed metals often behaves like water containing suspended matter does in freezing, when the ice first formed rejects the foreign matter; and so the portion of the alloy which first solidifies rejects certain other portions of the constituent metals. Thus a mixture of lead, antimony, and copper poured into a cylindrical mould, allowed to cool, and then broken, will show that while the copper and antimony have united the lead has been rejected, and driven to the centre of the mass. A mixture of lead and zinc separates in a similar way. Silver and copper alloys behave in a similar manner, but in any mixture of fused silver and copper, one particular alloy of silver and copper is formed, this is driven inwards or outwards according to whether copper or silver is in excess in the bath. In all cases the separation is never complete, a small quantity at least of the other metal being found in each portion of the separated constituents. The solid mass in the above three cases is a mixture of solidified solutions of the metals in each other.[1]

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[1] Matthiessen, *Brit. Assoc.* 1863.

Dr. Guthrie gave considerable attention to this subject some years ago, and came to the conclusion that certain alloys in cooling behave as a cooling mass of granite would; clear molten granite in cooling would throw off "atomically definite" bodies, leaving behind a fluid mass, which is not definite in composition, as the quartz and felspar solidify before the mica. The same thing takes place in cooling fused mixed metals; for when a mixture of lead and bismuth or bismuth and tin cools, a certain alloy of the metals falls out, and the most fusible alloy of the series is left, which Guthrie calls the *eutectic* alloy. It is the most fusible alloy of the series, but the proportions between the constituent metals are not atomic proportions; and Guthrie says, "that the preconceived notion that the alloy of minimum temperature of fusion must have its constituents in simple atomic proportions, and that it must be a chemical compound, seems to have misled previous investigators; but that certain metals may, and do unite with one another in small multiples of their combining weights may be conceded; the constitution of *eutectic* alloys is not in the ratio of a simple multiple of the chemical equivalents of the constituents, but their composition is not on that account less fixed, nor are their properties the less definite."[2]

"Matthiessen considers that the conductivity for heat and electricity are among the characters best calculated to indicate the chemical nature of alloys. With respect to electric conductivity, he divides metals into two classes:—

"A. Metals which, when alloyed with each other, conduct electricity in the ratios of their relative volumes—lead, tin, zinc, and cadmium.

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[1] Roberts-Austen, *Journal of Society of Arts*, 1888, p. 1115.

[2] *Phil. Mag.* June 1884, p. 462.

"B. Metals which, when alloyed with each other, or with a metal of class A, do not conduct electricity in the ratios of their relative volumes, but always in a lower degree than that calculated from the mean of their volumes—bismuth, antimony, platinum, palladium, iron, aluminium, gold, copper, silver, etc.

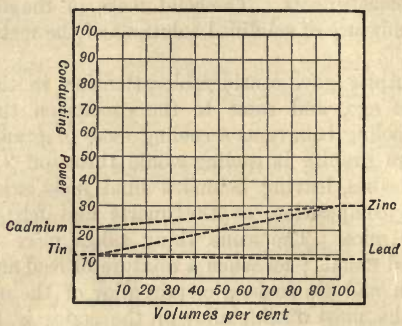

FIG. 1.

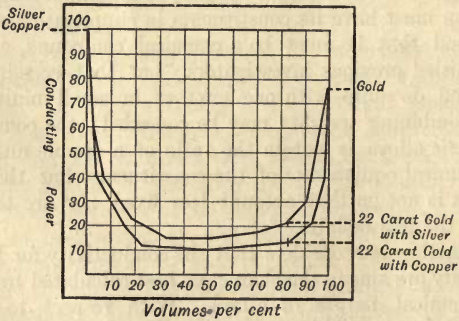

FIG. 2.

"The curves representing the conductivity of different series of alloys have the relation shown in the accompanying diagrams.

"Group I. Those belonging to the alloys of metals in class A are almost straight lines. That of lead-tin alloys is given as a type, Fig. 1.

"Group II. The curves of alloys of metals in class B show a rapid decrement on both sides of the curve, the turning points being connected together by nearly straight lines. That of gold-silver alloys is given as the type, Fig. 2.

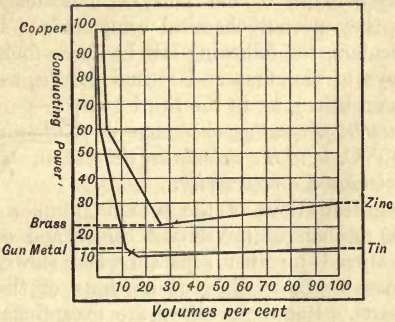

Fig. 3.

"Group III. The curves of alloys of metals in class A with those in class B show a rapid decrement on the side beginning with the metal belonging to class B, then turning and going in a straight line to the other side, beginning with metal belonging to class A. That of tin-copper alloys is given as the type, Fig. 3.

"In regard to alloys of the first group, if they were mechanical mixtures, the metals composing them, unless their specific gravities were the same, would separate into two layers when melted and slowly cooled, as in the case of lead-zinc alloys. But the alloys of lead and tin, for example, do not separate in the same way as lead and zinc. Moreover, homogeneous wires could not be obtained by pressing, if these alloys were mechanical mixtures; but wires of the same alloy have been proved to have the same conducting power, whether taken from the press at the beginning or end of the operation.

"On the other hand, the agreement between the theoretic and actual conductivity of these alloys, as well as between the calculated and actual percentage decrement in conductivity between 0° and 100° C., indicates that, in the solid state, they are not chemical compounds. In regard to these particulars, the following law has been found to obtain for all alloys of the first and second groups, as well as for some of those belonging to the third group:—

"*The actual percentage decrement in conductivity between* 0° *and* 100° C. *is to the calculated decrement, as the actual is to the calculated conductivity.*

"Among the alloys of the second group, some may be regarded as mechanical mixtures. Silver and copper fused and well stirred together separate when slowly cooled, so that the mass contains different amounts of the metals at different parts. But these alloys are exceptional, and most alloys of this group may be regarded as solidified solutions of allotropic modifications of the metals in each other.

"In the third group of alloys, the rapid decrement in the conductivity of those alloys of the several series, which contain but very small amounts of a metal belonging to class A, cannot be ascribed to the existence of chemical compounds of the metals. For, in the first place, the amount of one of the metals in the alloys corresponding to the turning-points of the curves representing the conductivity of the series is too small, as will be seen by the following instances:—

Alloy.	Percentage.
Bismuth-tin	Tin . . . . ·6
Bismuth-lead	Lead . . . 2·0
Silver-tin	Tin . . . 2·6

"Again, the great similarity of the curves representing the conductivity of the series of alloys belonging to this group is opposed to the existence of chemical compounds in the solid alloys.

"The influence exercised upon the conductivity of metals by the presence of small quantities of other metals, does not appear to be in any way determined by the alteration of crystalline form, or tendency to crystallise, which are known to be influenced by that circumstance.

"If it be assumed that the metals belonging to class B undergo a molecular change when alloyed with one another, or with metals belonging to class A, and that in each case an allotropic condition is induced by a small amount of other metals, varying with the different metals, then many of the phenomena characteristic of alloys may be explained. Thus the curve representing the conductivity of zinc-copper alloys has the same form as those of other alloys, belonging to the same group, and the percentage decrement in their conductivity between 0° and 100° C. is exactly what is indicated by the law above stated. Hence it may be inferred that solid alloys of zinc and copper are only solidified solutions of zinc, and of allotropic copper in each other. The different action of reagents upon alloys, and upon the metals constituting them, when in an isolated state, may also be referred to the existence of such allotropic modifications when they are alloyed, as well as to the existence of chemical compounds of the metals."[1]

SLAGS, FLUXES, AND REFRACTORY MATERIALS

§ 15. **Slags.**—The slags formed in metallurgical operations are, with few exceptions, produced by the union of silica with metallic oxides, and termed silicates. Silicates may be divided into two classes, viz. "hydrated," which contain water; and "anhydrous," which are free from water. The silicates produced by heat in metallurgical operations belong to the latter class. The bases most often found in slags from smelting ores are:—lime, magnesia, oxide of iron, and alumina. Both the silica and bases are derived from the earthy matter of the ore, the ashes of the fuel, the flux, and the material of which the furnaces or vessels are constructed. In melting and mixing base metals to form alloys, some of these elements oxidise and pass into the slag, and often form the chief bases when united with silica, or other acid substances.

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[1] Watt's *Diction. of Chem.* vol. iii. pp. 943, 944.

The silicates most frequently produced are those with an iron base, of which the most fusible is the protosilicate $2FeO . SiO_2$. The protosilicate of manganese appears to have about the same fusing point as the protosilicate of iron; it has an olive-green colour, is opaque, and but slightly crystalline. It does not absorb oxygen in contact with air like the silicates of iron, and cannot therefore be employed as an oxidising agent. A double or multiple silicate containing two or more bases is often more fusible than a single silicate; hence a compound silicate of lime, magnesia, alumina, etc., is more fusible than either of these bases combined alone with silica, and melts readily when strongly heated. Likewise, oxide of manganese augments the fusibility of earthy silicates.

Oxide of zinc forms single silicates, which are practically infusible, and, as a general rule, this oxide diminishes the fusibility of silicates of iron, lime, etc. Protoxide of tin augments the fusibility of multiple silicates. The proto- and bi-silicates of copper melt easily; they augment the fusibility of earthy silicates. Oxide of copper is easily separated, especially in the presence of sulphur or arsenic, with which it forms regulus or speise respectively. The oxides of lead and bismuth are, next to the alkalies, the most fluxing bases. Silicates of lead melt at a red heat. Oxide of lead increases the fusibility of multiple silicates, but it is easily reduced by the presence of metallic iron.

Slags are either vitreous or stony, and not infrequently they are more or less crystalline. Rapid cooling tends to produce the glassy variety, and by slow cooling the crystalline structure is induced. The stony condition is prevalent in slags in which earthy bases predominate. The object in forming slags in melting metals is to form readily fusible compounds, which shall contain the impurities it is desirable to remove, and at the same time be as free as possible from the metal or metalliferous substance undergoing preparation. When the slag is free from useful metals, it is said to be clean; but when a slag contains useful ingredients it is often advisable to remelt it with another charge, so as to extract valuable components, and render it sufficiently clean to be thrown away. It frequently happens that the slags produced in dealing with a given kind of metalliferous matter are useful as a flux or other agent in extracting or melting different metals.

When the charge is improperly prepared, and either silica or lime predominate, or when the amount of alumina or magnesia is very large, or the temperature insufficient, the slags are imperfectly melted, and present a kind of granular fracture.

§ 16. **Fluxes.**—A flux is a substance added to metalliferous matter, in order to unite with the foreign ingredients, and form a fusible slag. The flux employed in any given case varies with the nature of the bodies to be removed. Thus, if the impurity be of an acid nature, such as silica, the flux should be basic or neutral. If, on the other hand, a basic substance has to be separated, an acid flux will be generally required. In many cases of simple melting of metals it is desirable to remove foreign metals, which are present as impurities; it is then advisable to add an oxidising flux, in order first to oxidise the impurities, in which state they readily combine with an acid flux to form a liquid slag, or volatilise, or simply rise to the surface in virtue of their lower specific gravities.

It frequently happens that a slag is formed at one stage of an operation, and decomposed again by the action of some reducing agent present. With regard to silicates, the most difficult to reduce are those with earthy bases, such as lime, magnesia, alumina, etc. When a slag contains several oxides, the most feeble bases will be reduced first, and the others in the order of their basicity. Suppose a compound silicate to contain the oxides of manganese, iron, tin, and lead; the oxide of lead will be the first to be reduced, then the oxide of tin, then the oxide of iron, and lastly the oxide of manganese. The composition of silicates has a marked influence upon their consistence when melted. The bisilicates, or silicates with an excess of silica, pass gradually from the solid to the liquid state, or conversely from the liquid to the solid state; they preserve for a long time a "viscous" or "plastic" consistency. The protosilicates or basic silicates, on the contrary, pass more or less quickly from the liquid to the solid state, and on cooling they set rapidly. They are very liquid when melted, and crack at the moment of solidifying.

The most fusible silicates are formed by union of silica with fusible bases, such as soda, potash, oxide of lead, oxide of bismuth, etc.; and the silicate formed is fusible in proportion to the amount of base present. With infusible bases, on the contrary, the fusibility is greatest when neither acid nor base is in excess. Baryta BaO is more fluxing than lime CaO, and magnesia MgO is still less fluxing than lime. Alumina Al_2O_3 is, among the common bases, the least fluxing.

Fluor-spar CaF_2 has a wide and well-deserved reputation as a flux. At a high temperature it melts into a transparent liquid. It is partly decomposed by silica, with the liberation of the gas silicon fluoride, but the greater part is found in the slag, in which it favours fusion and fluidity. When the bodies to be fluxed off are sulphates of lime, baryta, strontia, and bone-ash (phosphate of lime), fluor-spar is specially useful. A tenth part of fluor-spar is sufficient to liquefy sulphate of lead at a bright red heat.

Sulphur is often present in metalliferous substances, in the form of sulphides, such as silver sulphide, for example.

In that case metallic lead may be employed, which decomposes the sulphide of silver, forming sulphide of lead, and isolating the silver, which then unites with the excess of lead. In the same way iron decomposes lead sulphide, forming sulphide of iron and metallic lead. The metals of the alkalies and alkaline-earths are very effectual in removing sulphur from metallic sulphides. The metals are obtained for this purpose by reducing their oxides by carbonaceous matter in admixture with the metallic sulphide. In this case an alkaline sulphide is generally formed, together with an oxide of the metal. In some instances the decomposition of the metallic sulphide is incomplete. Certain sulphides, such as zinc sulphide, are rendered fusible by the addition of sulphide of iron, or iron pyrites. Many sulphides are fusible alone; and in most cases it is easy to transform them into oxides by roasting in atmospheric air, or by fusion with an oxidising flux.

When litharge PbO is melted with sulphides and arsenides, sulphurous and arsenious acids are volatilised, and an alloy of the metals with lead is formed. Other metallic oxides act in a similar manner, but, as a general rule, the sulphide is more or less converted into oxide, depending upon the amount of oxide used, and the relatively chlorous and basylous characters of the metals, and of sulphur and oxygen.

Lead carbonate acts on sulphides in the same way as lead oxide. Lead silicate is also oxidising, but in a less degree, the slags produced containing both metals. Lead sulphate is more oxidising than litharge. When it is melted in the right proportion with sulphide of lead, the whole of the lead is reduced. Copper and iron sulphates are generally oxidising agents for sulphides. Nitrates, such as saltpetre KNO_3, are the most powerful oxidising agents in melting operations. Basic iron slags are very active agents in promoting oxidation. For example, when iron containing carbon, silicon, sulphur, and phosphorus is strongly heated with basic silicate of iron these impurities are largely oxidised, forming carbonic oxide, silica, sulphurous acid, and phosphoric acid.

Following is a list of the most common fluxes, with a brief account of their properties and uses :—

1. *Ammonium chloride* (AmCl) called sal-ammoniac. This substance is decomposed by several metals forming metallic chlorides and liberating ammonia, which property is taken advantage of in purifying gold. A similar reaction occurs with several metallic salts.

2. *Sodium chloride* (NaCl) or common salt, is employed for preserving the substance beneath from the action of the atmosphere, and to moderate the action of bodies which cause violent ebullition. It melts and volatilises at a red heat in an open crucible, but requires a white heat to vaporise it in a closed vessel. When heated to redness with silica it forms a readily fusible silicate. It forms fusible compounds with antimony and arsenic, thus removing them from other metals during the process of refining. As the crystals decrepitate when heated, common salt should be powdered before using as a flux.

3. *Borax* ($B_4O_7Na_2$).—In the crystalline form it may contain 5 or 10 molecules of water, which are given off on heating, causing an enormous increase in volume, so that the vitrified form is much more suitable for assaying. It forms fusible compounds with silica, and nearly all bases, being especially useful in uniting with metallic oxides, sulphides, and arsenides. The commercial salt is adulterated with common salt and alum.

4. *Sodium carbonate* (Na_2CO_3) has the property of oxidising many metals, such as tin, iron, zinc, etc., by the action of its carbonic acid, and as a consequence of this action it acts as a desulphuriser. It forms fusible compounds with silica and many metallic oxides; it also melts at a low temperature, absorbing many infusible substances, such as lime, alumina, charcoal, etc. In some cases it acts as a reducing agent, as in the case of chloride of silver. When mixed with carbonate of potash a double salt is formed, which fuses at a lower temperature than either taken alone, a property very useful in the fusion of silicates, etc.

5. *Potassium nitrate* (KNO_3), also called nitre and saltpetre, is largely used as an oxidising agent. It fuses below redness, and at a higher temperature is decomposed, yielding a large volume of oxygen, whereby the sulphur of metallic sulphides is converted into sulphurous acid, and the metals into oxides. Sodium nitrate acts in the same way.

6. *Potassium bitartrate* ($\overline{T}HoKo$), known also as cream of tartar or tartar. When pure this substance is white, but the variety chiefly used on the large scale is coloured, and sold as red "argol"; this is cheaper, and contains other carbonaceous matters, which give it greater reducing power than pure cream of tartar. This reagent is very valuable in operations requiring much carbonaceous matter.

7. *Potassium chlorate* ($KClO_3$).—This substance is sometimes used with nitre as an oxidising agent, especially in assaying.

8. *Potassium cyanide* (KCN).—This flux is valuable on account of the facility with which it fuses, and the readiness with which it reduces many metallic compounds when mixed with carbonate of soda. Common cyanide is preferable as a reducing agent, because it contains carbonate of potash.

9. *Calcium oxide* (CaO) or lime, is used in the caustic state, or combined with carbonic acid in the form of carbonate. It is a useful flux for silica and silicates; and is also used to remove sulphur and phosphorus from metals and their compounds.

10. *Calcium fluoride* (CaF_2) or fluor-spar. This substance acts as a flux in two ways—(1) by combining with silicates, forming fusible compounds; (2) by reacting with silicates and evolving the gas silicon fluoride SiF_4. It forms fusible compounds with sulphates, such as plaster of Paris, and with phosphate of lime (bone-ash). It should be free from pyrites, blende, and galena, with which it is likely to be contaminated.

11. *Lead oxide.*—There are two oxides of lead of importance in treating metals, viz. litharge PbO, and red-lead Pb_3O_4. Both oxides are reduced by carbon or hydrogen,

producing metallic lead. Lead oxides, when melted, oxidise nearly all metals, except mercury, gold, silver, and platinum. With other oxides they form easily fusible compounds. When heated with sulphur, lead oxides are reduced, and sulphurous acid is liberated. When oxide of lead in sufficient quantity is melted with an infusible silicate, a fusible double silicate is formed.

12. *Manganese dioxide* (MnO_2).—This substance is black in colour, opaque, and a good conductor of electricity. When heated alone it is infusible, but gives off oxygen, forming Mn_2O_3 or Mn_3O_4, according to the degree of heat employed; heated with charcoal it is reduced to MnO. The facility with which it gives up oxygen makes it a valuable oxidising agent. With hydrochloric acid it is extensively used for generating chlorine. When strongly heated in a crucible lined with a paste of carbon it is reduced to the metallic state.

13. *Silica* (SiO_2).—This body occurs in crystalline and amorphous forms; it is white, infusible, except at the very highest temperatures, non-volatile, insoluble in water and acids, except hydrofluoric; after ignition, it is decomposed by carbon in the presence of iron, copper, or silver at a white heat, forming silicides of those metals. The amorphous and gelatinous varieties are slightly soluble in alkaline carbonates, but readily soluble in caustic alkalies. It combines with all the bases forming silicates, and is therefore frequently employed to effect the fusion and separation of gangues in ores, the best forms to use being pure white sand and quartz.

14. *China clay* is essentially a hydrated silicate of alumina, and when pure may be represented by the formula $(2Al_2O_3, 3SiO_2) + 3OH_2$; but clay is generally mixed with other silicates. It is white, and infusible in an ordinary furnace when heated alone, but readily unites with earthy and metallic gangues to form a fusible slag.

15. *Glass* is a mixture of silicates of sodium and potassium with some insoluble silicate, such as silicate of barium, mag-

nesium, aluminium, iron, or lead. Being a compound silicate it fuses easily at a high temperature, and readily combines with lime and other bases containing little or no silica, so that it is often preferred to pure silica, and serves to economise borax. It is also employed as a covering in melting metals, so as to exclude the air. Plate or window glass, or green bottle glass is the most useful, but flint glass, which contains much oxide of lead, would be detrimental in many cases.

16. *Ferrous sulphide* (FeS) is chiefly used as a source of sulphuretted hydrogen. Roasted with easily decomposable sulphides, such as that of silver, it converts them into sulphates. Heated with oxides of copper, nickel, etc., it forms regulus. Heated in air it is oxidised to sulphate, and at a high temperature to oxide.

17. *Iron pyrites* (FeS_2).—This body loses half its sulphur at a white heat, forming ferrous sulphide, and is used for similar purposes to that compound. It is chiefly employed in the metallurgy of copper, nickel, and cobalt.

18. *Ferric oxide* (Fe_2O_3).—This oxide is very stable, non-volatile, and of a red colour. At a white heat it gives up oxygen, forming Fe_3O_4. By heating with carbon, or carbonic oxide, it is reduced to the metallic state, but if much carbonic acid is present, ferrous oxide may be formed, which combines with any silica present, forming a fusible silicate. For this reason it is sometimes used as a flux. In refining iron it acts as an oxidising agent. In presence of sulphur it oxidises that element to sulphurous acid.

19. *Zinc oxide* (ZnO) is a powerful base; it forms combinations with alkaline earths and several bases, and has a strong affinity for alumina. It is reduced by carbon, carbonic oxide, and hydrogen. Zinc oxide and carbon in small quantity is added to molten copper for producing sound castings.

REFRACTORY MATERIALS

§ 17. For melting metals a furnace is required, built of, or at least lined inside with, a material capable of withstanding high temperatures without fusing, or softening, or decomposing by the heat to which it is subjected. As a rule the exterior is constructed of ordinary masonry, but the interior is lined with refractory material, the nature of which depends to a great extent upon the character of the operation to be performed in it. Refractory materials are either used in the natural state, such as silica, alumina, oxide of iron, magnesia, and fire-clay, or they undergo a preliminary preparation before use. In some cases the materials are moulded to the internal shape of the furnace. If they are not of a plastic nature like fire-clay, then clay, tar, or other binding material is intimately incorporated with them, in order to impart the necessary plasticity.

Quartz or Silica.—This substance neither softens nor melts at the highest furnace temperatures, and is therefore a valuable material for internal construction, either when mixed with refractory clay to form silica bricks, or when used alone as a lining for the beds of reverberatory furnaces. Sand is not composed of pure silica, but the small quantities of lime, oxide of iron, and clay usually present are not objectionable. Dinas clay is a highly refractory substance, occurring in the Vale of Neath, and contains about 97 per cent of silica, the remainder being lime, oxide of iron, alumina, alkali, and water. From this material, when mixed with 1 to 3 per cent of lime, bricks are made, which form valuable linings for the roofs of many reverberatory furnaces.

Alumina is quite as infusible as silica, and has the advantage of not generally combining with bases, and when it does so combine the aluminates formed are less fusible than silicates. But pure alumina is rarely found in nature, the nearest approach to it in large quantity is bauxite, which Berthier found to consist of 52 per cent alumina, 27·6 oxide of iron, and 20·4 per cent water; but the composition varies in different specimens. The ordinary mineral contains 3 to 5 per cent silica, 24 to 25 per cent oxide of iron, 50 to 60 per cent alumina, and 10 to 15 per cent water. It is generally dark red in colour like an iron ore, but some varieties exist with but little iron, and are then white in colour and very refractory.

Lime and Magnesia.—These are infusible bodies, strongly basic in character, but they form fusible compounds with silica and other acid bodies. This property is utilised in some steel furnaces, the interiors of which are lined with these oxides, which abstract phosphoric acid from the iron, forming stable phosphates. Lime and magnesia occur together in dolomite, from which material, after calcination, basic bricks are prepared.

Fire-Clay.—The refractory bodies already referred to may combine together in certain proportions, without ceasing to be refractory. Fire-clay is a hydrated silicate of alumina with varying amounts of lime, magnesia, oxide of iron, alkali, etc., and some mechanically mixed silica. The plastic property which clays possess is due to the chemically combined water. In all cases the plasticity disappears when the clay has been baked, and it remains granular and powdery. The clays of the coal-measures, such as those of Stourbridge, are admirably adapted for making fire-bricks, although not pliant enough for pottery. In fact an excess of plasticity is a disadvantage for some metallurgical purposes, as bricks, for example, would crack at the time of baking.

§ 18. **Crucibles, etc.**—Earthen crucibles are made of fire-clay mixed with sand, burnt clay, or other infusible matter, so as to counteract the tendency which raw clay possesses of shrinking when heated. The bodies thus mixed with the clay expand, or do not contract on heating, having been already shrunk when burnt, and therefore act in an opposite manner to the clay. Such a composition must be able to resist a high temperature without softening, must not be friable when hot, and be capable of withstanding sudden changes of temperature without cracking, as, for instance, when a white hot crucible is brought out of a furnace into cold air.

Some crucibles are required to resist the corrosive action of metallic oxides in the material operated upon, and in the ashes of the fuel, so that a crucible should be selected which is best adapted to the special purpose to which it is to be applied.

The component parts of a crucible are first crushed to a fine powder, and passed through a sieve, the fineness of whose meshes will vary with the desired fineness of the grain in the pot (the plasticity being closely connected with the fineness of the particles; at any rate for small crucibles this closeness of grain appears to be indispensable), then the fine powder is mixed with water and kneaded to the right consistence for use. The best results are obtained by using a mixture of different fire-clays, the most infusible being those containing the largest amount of silica, and the minimum of oxides of iron and lime. The presence of potash and soda in small quantity sensibly increases the fusibility, but they act advantageously in soldering the particles together. Iron pyrites, which is frequently disseminated through clays, especially those from the coal measures, is perhaps the most injurious constituent. A crucible made from such clay will become indented with small cavities, and even holes, when exposed to a prolonged high temperature. It follows then that the most refractory crucibles are those made from pure clays, the nearest approach to which is presented by some French clays.

The fitness of a clay for making crucibles may be determined by moulding a portion into the shape of a prism, or any form containing sharp edges, carefully drying, baking, and exposing to a high temperature in a covered crucible for some time. If very refractory, the test will show no signs of fusion. If the edges are rounded it is a proof of incipient fusion, and if melted, the clay is useless.

Clay vessels of all kinds may be tested to ascertain their power of resisting corrosion by melting in them a mixture of litharge, red oxide of copper, and borax, and noticing the time this mixture will take to permeate them. Those which resist this destructive action the longest will of course be the best. Most crucibles are by this means eaten away irregularly, showing the necessity of uniformity of grain to resist perforation.

All crucibles should be cautiously annealed before use by placing them in an inverted position over the furnace, otherwise they are liable to split when plunged into a red-hot fire. I have noticed this tendency with the best plumbago crucibles.

Plumbago or black-lead pots are made from varying proportions of fire-clay mixed with powdered graphite or coke dust. Good graphite is neither altered nor fused by exposure to the highest temperatures (air being absent), so that it is an admirable substance for crucibles. The graphite is powdered, sifted, and mixed with sufficient clay to render it plastic. Good plumbago crucibles, after a careful preliminary annealing, withstand the greatest changes of temperature without cracking, and may be heated many times in succession.

When an ordinary crucible requires to be protected from the corrosive action of metallic oxides, or when small amounts of metallic compounds have to be reduced, the inside is coated with a lining of charcoal. This is done by first mixing the charcoal with sufficient starch, paste, or treacle to make it adhere when pressed. The crucible is then loosely filled with the brasque, and a cavity of the desired size made by boring with a triangular-shaped piece of wood, and then made smooth with a round elongated wooden tool, whose size and shape are apportioned to the capacity of the cavity desired, or the brasque may be plastered on the inside of the crucible by the hand.

§ 19. **Fire-Bricks.**—A fire-brick used to withstand high temperatures must only contain small quantities of the alkalies, which should not exceed 1 per cent. Glenboig, Stourbridge, and Wortley (Leeds) are the leading brands extensively used; these are safe, though of course there are many other fairly serviceable bricks made of brands less in repute.

Ganister bricks are exceedingly valuable for withstanding the very highest temperatures for the crowns of reverberatory furnaces. They do not crack on cooling so much as bricks composed almost entirely of silica. The *Lowood* brick, made near Sheffield, has a very high reputation in this class. Ganister bricks should be set in thin ganister cement. Crowns are best put on dry, and just "slurried" over the top when finished. No fire-brick has a fair chance if set in a clay inferior to itself; but however excellent the clay, a good furnace builder will use as little as possible.

Dinas bricks are practically infusible, and composed almost wholly of silica. The fractured surface presents a coarse, irregular structure of a light-brown colour. The lime which is added exerts a fluxing action on the particles of quartz, and so causes them to agglutinate (see also p. 58).

Mr. James Dunnachie in a paper read before the British Association said: "The great variety of purposes for which fire-bricks are used, and the various qualities required in them, make it impossible that one brick can answer for all descriptions of furnaces. They require to stand strong heat and changes of temperature; in some cases heavy pressure and hard knocks; in others they require to resist the fluxing and chemical actions of various kinds.

"A brick high in silica, containing a fair proportion of alumina, and nearly free from alkalies and other impurities, is the one which combines, in the highest degree, infusibility and freedom from cracking. To get a really good furnace, we must first procure the best materials for its construction; but after that much depends upon how it is built. If we were as careful about the curves of our furnaces as we are about the lines of our ships, and as particular about the quality of the materials and workmanship employed as the importance of the subject demands, we might, in many cases, double the duration of our furnaces, without waiting for the possible discoveries of the future."

The following analysis will serve to show the composition of British materials used in furnace construction:—

	Silica.	Alumina.	Ferric oxide.	Lime.	Magnesia.	Potash and soda.	Titanic acid.
Fire-brick, Glenboig . .	64·41	30·55	1·70	·69	·64	·55	1·33
,, Stourbridge .	73·05	22·40	2·43	·39	·54	1·09	..
,, ,, .	77·63	19·48	1·29	·18	·31	·91	..
,, Newcastle . .	73·30	20·56	1·69	1·55	·72	2·50	..
,, ,, . .	58·00	36·50	1·67	·58	·82	2·42	..
,, Pensher . .	65·10	30·03	2·00	·45	·51	2·04	..
,, Flintshire . .	88·10	4·50	6·10	1·2	..	..	..
,, Leeds . . .	77·30	19·17	1·43	·45	·63	1·20	..
,, ,, . . .	72·65	23·75	1·75	·30	·36	·90	..
,, ,, . . .	67·40	25·56	2·00	1·12	·72	2·47	..
,, Elland . .	62·33	35·59	1·25	·73	·10	..	..
Ganister bricks, Lowood .	96·32	·99	·71	1·28	·25	·26	..
,, ,, Witton .	94·80	·89	1·10	2·85	·32	·30	..
Dinas bricks, Wales . .	95·16	·42	·33	2·96	·28	·29	..
						Manganous oxide.	
Burnt Dolomite, Raisby Hill	5·60	2·35	1·70	54·56	34·18	1·2	..
Ganister, Lowood . .	89·55	4·85	1·28	..	·80	3·52	..
,, Weardale . .	85·53	9·10	·64	·73	·40	1·05	..

PREPARATION AND PROPERTIES OF ALLOYS

§ 20. The mode of procedure in the production of any alloy will be largely influenced by the nature of the metals to be operated upon. Some metals are volatile, and readily pass off as vapour when heated a few degrees above their melting points. Others have little tendency to vaporise, and may be raised to high temperatures without sensible volatilisation. When a volatile metal has to be alloyed with a non-volatile metal, and the fusing points of both are approximately the same, combination can be most readily effected by mixing the constituents and melting them together in the same crucible or furnace. This is, however, seldom the case, and, as a general rule, the components of an alloy, one or all of which are volatile, have widely divergent melting points, and then it is requisite for the most refractory constituent to be melted first, and for the others to be added in the solid state. Again, an alloy may contain one or more fixed metals and a volatile one, in which case the more volatile metal is added to the crucible, after the fixed metal or metals have been fused, and raised to a temperature necessary to melt the volatile constituent immediately it is introduced, so that combination may be effected before any serious loss, due to vaporisation, has occurred. Union between the components of an alloy is more perfectly secured by agitation of the contents with a stirring-rod, the most effective in many cases being a wooden or carbon rod, which promotes admixture without the introduction of any substance likely to contaminate the mixture, and modify its properties.

A thing to be guarded against in the melting of all base metals, or alloys containing base metals as essential constituents, is oxidation. Various plans are adopted to avoid loss of metal and injury to the alloy from this cause. The most common one is to cover the metals with carbon, which not only excludes the air admitted to the furnace, but tends to absorb any oxygen liberated from the metals during fusion. The gas thus formed by union of carbon with oxygen is termed carbonic oxide CO, and this gas being a reducing agent, is capable of taking up another atom of oxygen, forming carbonic acid CO_2. Thus, as long as the mixture is covered with carbon, the carbonic oxide formed effectually shields it from oxidation. In the method already referred to of stirring metals with a carbon rod to promote mixture, the same gas, carbonic oxide, is formed, and thus the rod not only promotes union by mechanical agitation, but generates a gas which protects the metals in a great measure from oxidation. In some cases this is not admissible, as commercial metals are impure, and it may be advisable to admit sufficient oxygen, either from the air or by means of a special oxidising agent, added along with the flux, to convert the impurities into oxides, which do not alloy with the metals, but either enter into combination with the flux to form a slag, or rise to the surface as dross or scum. In most cases it is advisable that the covering body should not exert any influence on the metals beneath.

Some manufacturers are in the habit of throwing fat and resin on the heated metals before fusion. These are decomposed by the heat, liberating gases, and when well stirred with the molten metal promote combination by the mechanical agitation imparted by their escape. They also act chemically in removing oxygen, by the union of that element with the carbon and hydrogen set free. When the evolution of gas has ceased, a quantity of carbon remains in a finely divided state, which covers the metals and protects them from oxidation.

Borax is sometimes used to exclude the air, but it is much more costly than carbon, and when it is not required as a flux, its employment is accompanied with some evils. Now borax is composed of the base soda in combination with boric acid, which is only partly saturated with the soda, and the excess of acid unites with any metallic oxide present forming double borates, of a glassy nature. Commercial borax is often very impure, and is adulterated with common salt and alum; these impurities are injurious to many metals. Sodium chloride or common salt is also employed for preserving molten metals from oxidation, and also to moderate the action of bodies which cause violent ebullition. Glass is frequently used for a similar purpose, and next to carbon is the least injurious to metals. It is a mixture of silicates, which easily fuses at high temperatures, forming compounds with lime and other bases, so that it acts almost as beneficially as borax when such a flux is required. Window glass or green bottle glass is the most useful, but flint glass, which contains much oxide of lead, would be detrimental in many cases.

The nature of metallic alloys has already been discussed, from which we may assume that certain proportions of the constituents enter into chemical combination, and other portions are simply in a state of mixture or solution, and therefore, on gradually cooling, tend to separate in distinct layers according to their respective densities. This is especially the case when the constituents have widely divergent densities, so that the higher the temperature of the alloy when removed from the furnace the longer will the period of cooling last, and the greater will be the facilities offered for separation. To obviate this defect the metal should be constantly agitated by stirring or otherwise, and poured into the moulds at the lowest temperature consistent with the requisite fluidity; and cooled as rapidly as the nature of the alloy and the purposes for which it is designed will admit. With regard to the melting point of an alloy, it should be borne in mind that it fuses at a lower temperature than that at which the most refractory constituent melts, and sometimes below that of either, which knowledge should guide the operator in so regulating the temperature as not to make the charge unnecessarily hot.

It is a well-known fact that the character of many alloys is altered by repeated remelting, and that the scrap obtained in working cannot be used again without the addition of a certain quantity of new metal. A given mixture may be employed for the formation of an alloy, which is highly malleable, ductile, and tenacious, and the scrap from the same alloy when remelted may be brittle and unworkable; but when a suitable quantity of new metal is added, the combination may form an alloy even superior to the original one with regard to its good working properties. It is to the advantage of the manufacturer as regards economy, to use as much scrap as possible in alloying, and the quantity thus employed varies from one-third to two-thirds of the weight of the charge. Of course, in using old metal many more impurities are liable to be introduced than with new metal, and although the same impurities may exist in the new metal, the quantities may be insufficient to produce a deteriorating effect, but when augmented from old metal may then rise to such proportions as to entirely alter the physical properties of the alloy. The presence of notable quantities of foreign matter is generally exhibited by increased hardness and a modification of the structure, as seen on a freshly fractured surface.

The difficulty of maintaining uniformity in an alloy after repeated remelting is least when only two metals are mixed together, and increases when the combination requires the presence of three or more metals. Thus German silver requires much greater care in this respect than brass; and soft solder, containing only lead and tin, requires less care than fusible alloy, containing bismuth or cadmium in addition to lead and tin. Those alloys, which contain as an essential constituent a volatile metal, such as zinc or antimony, are generally altered most by remelting, and it is requisite to know, at any rate approximately, what the furnace loss is, so that the defection may be counterbalanced by the addition of the quantity of fresh metal requisite to maintain the right composition. Many errors arise from this cause, as well as from overdoing what is required. Where possible, a chemical analysis is the best means of solving the problem, but as this is out of the question in most cases, a few simple trials with weighed quantities, and careful observations of the results obtained, by testing its malleability, colour, and fracture, will generally afford sufficient evidence of the required amount to be added.

In making experimental tests, a small melting furnace, such as that used in a metallurgical laboratory, a strong pair of hand rolls, and an anvil would be very useful adjuncts to every casting shop. The quantity of metal operated upon need not exceed one pound in weight, and as this could be cast in a long strip, its suitability for stamping or rolling could be readily tested. Such test-pieces, if carefully labelled and preserved, would be most valuable for future reference, and there can be no doubt that both employers and employed would thus gain a vast amount of information, which would prove of great benefit both as a standard of workmanship and of economy of production. It is a common experience to find, after a quantity of metal has been mixed and the castings made, that the alloy is unsuitable for the work required of it, either from unsuitable constituents, improper mixing, or impure materials; which annoyance could be avoided by a few preliminary trials on the small scale. The casting of such trial tests could be made in an iron or sand mould, and the time of cooling made to approximate to that of a large mass by judicious treatment. Another advantage of such an experimental plant would be that new combinations could be readily tried, and the effect of certain impurities on well-known alloys ascertained, by purposely adding these bodies in definite amounts to a weighed quantity of the alloy.

The purposes for which alloys are required are endless. Some are required to possess great malleability, for others hardness is the chief requisite; others, again, must possess a high degree of elasticity, while some are useful on account of their low melting point, etc. These different demands can only be satisfied by uniting suitable metals in different proportions.

The metals most often used for alloying at the present time are those which have been known the longest, such as copper, zinc, lead, tin, gold, and silver; and although combinations of these metals have been known and employed for many centuries, it is only during the latter half of the present century that their intimate properties have been closely studied. Indeed, at the present day our information concerning the nature and properties of alloys is perhaps less than in any other branch of chemical science, and although chemical investigation may do much to enlighten our knowledge, such information will be destitute of great commercial value, unless accompanied with practical knowledge of the working, from observation of the physical properties, when alloys are worked in large quantities, by the manufacturers themselves. The number of simple metals is very limited, but they may be united in various proportions, forming an endless variety of modifications; and since every alloy may be looked upon as a new metal, from the fact of its properties differing from those of its constituents, we have at command the necessary material for producing metals suitable for every requirement for which metallic matter is desirable. The action of metals upon each other is widely divergent; sometimes one metal may be added to another in quantity without seriously altering its working properties; in other cases a minute quantity of a second metal will altogether change the character of the first metal; so that in alloying it by no means follows, because one metal may be freely added, that another, even of a similar nature, may be as liberally introduced. The man who aspires to the formation of new alloys, or who wishes to produce metals suitable for different requirements as circumstances arise, must be well acquainted with the nature and properties of the simple metals in order to successfully accomplish his object; and although a knowledge of the components is not sufficient of itself, it is of immense advantage in assisting the operator who combines practical experience in mixing metals with this theoretical knowledge. It is for these reasons that a brief account of the elementary metals is included in this work.

In chemical combinations it is a well-known fact that elements always combine with other elements in definite proportions by weight, termed atomic weight, producing compounds of fixed and decided properties, so that the same compounds can be always relied upon to contain the same elements, united in the same proportions. This same law applies to the union of two metals, when such metals are chemically combined, and the same alloy will always have properties identically the same, however it may be tested. Several experimenters have directed their attention to the mixing of metals according to their atomic weights, so as to obtain alloys of determined characteristic properties, but up to the present time the number of such combinations of a useful character is very limited. They are by no means the ones most suited to the wants and requirements of industry. There is always one indispensable item from the manufacturer's point of view which the chemist is not concerned with—that is, the cost of production—and however nicely atomic proportions would suit the requirements of a given alloy, such an alloy would in most cases be useless unless the cost was consistent with the market value. The question then of cost must have consideration, and the proportions must, if possible, be made to fit in with commercial necessities. With regard to copper alloys, such as brass and bronze, the combinations which best exhibit the characters of chemical compounds are hard and brittle, and as copper alloys are much more widely used than any other, there is little inducement to encourage metallurgists to endeavour to alloy copper and zinc, or copper and tin in atomic proportions, since malleability and tenacity are the properties most desired in these alloys. Again, colour is the chief desideratum in many alloys, and this cannot be always obtained by mixing in atomic proportions, especially as it often happens that a very small addition of one of the constituents will alter the shade of colour, so as to produce what is required.

When it is desirable to add a non-metallic element to a metal or alloy, for the purpose of bringing about a certain result, very much greater care is generally required in apportioning the quantity to be added than with a metal, as non-metals combine much more actively with metals than the metals do with each other, and a very small quantity of a non-metal will suffice to alter the properties of a metal or alloy. It is very surprising to note how, in some instances, a mere trace of another element will alter the properties of a metal. For example, $\frac{1}{2000}$ of carbon added to iron will convert it into mild steel; $\frac{1}{1000}$ of phosphorus makes copper hot-short; $\frac{1}{2000}$ part of tellurium in bismuth makes it minutely crystalline; $\frac{1}{1000}$ part of antimony in copper renders it exceedingly bad in quality for certain purposes.

Lothar Meyer has shown that a remarkable relation exists between the "atomic volumes of the elements." The relative atomic volumes of the elements are found by dividing their atomic weights by their specific gravities. The atomic weight of lead is 207, and its specific gravity 11·45; $\frac{207}{11 \cdot 45} = 18$, the atomic volume of lead. It would appear that the power of an element to produce weakness in a metal, when added in small quantity, is dependent on the atomic volume of the impurity.[1] Roberts-Austen tried the effect of various elements on pure gold, and found that when the body added had an atomic volume equal to, or less than that of gold, the strength was little affected, and in some cases, as copper for example, was increased; but when the element added had an atomic volume much greater than that of gold the strength, with two exceptions, was greatly diminished. His results are embodied in the following table:—

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[1] *Journal of Soc. of Arts*, 19th October 1888.

	Tensile strength.	Elongation per cent on 3 inches.	Impurity per cent.	At vol. of impurity.
K . .	less than ·5	not perceptible	less than ·2	45·1
Bi . .	·5	,,	·21	20·9
Te . .	3·88	,,	·186	25·5
Pb . .	4·17	4·9	·240	18
Thallium	6·21	8·6	·193	17·2
Sn . .	6·21	12·3	·196	16·2
Sb . .	6·0	?	·203	17·9
Cd . .	6·88	44·0	·202	12·9
Ag .	7·1	33·3	·2	10·1
Pa . .	7·1	32·6	·205	9·4
Zi . .	7·54	28·4	·205	9·1
Rh .	7·76	25·0	·21	8·4
Mn .	7·99	29·7	·207	6·8
In . .	7·99	26·5	·29	15·3
Cu . .	8·22	43·5	·193	7·0
Li . .	8·87	21·0	·201	11·8
Al . .	8·87	25·5	·186	10·6

Alloys generally have properties differing from their constituents, and some have these differences very strongly marked, thus: if a very small quantity of arsenic be added to tin, the resulting alloy will have a crystalline fracture closely resembling zinc. Sometimes metals combine with evolution of heat and sometimes with an absorption of heat. The following metals, according to Roberts-Austen, evolve heat when they are united :—aluminium and copper, platinum and tin, arsenic and antimony, bismuth and lead, gold and just melted tin. On the other hand, lead and tin when they unite absorb heat.

When lead, tin, and bismuth in equivalent proportions, and very finely divided, are mixed with eight equivalents of mercury, at the ordinary temperature, the temperature will fall from 17° C. to – 10° C. If the vessel containing the mixture stand on a wet board the water underneath will be frozen. This combination then will form a freezing mixture.

The method of producing alloys by strongly compressing the powders of the constituent metals was shown by Professor Spring of Liège in 1878, and he has since devoted much study to the subject.[1] His experiments were made by the aid of a press, the form of which is shown in Fig. 4. The metallic powder is placed under a short cylinder of steel, in the cavity of a steel block divided vertically, held together by a collar, and placed in a chamber of gun-metal, which may be rendered vacuous. The pressure is applied to a cylindrical rod passing through a stuffing-box. Under a pressure of 2000 atmospheres, or 13 tons to the square inch, lead, in the form of filings, becomes compressed to a solid block; and under a pressure of 5000 atmospheres the metal flows through all the cracks of the apparatus like a liquid. Spring obtained some important results with crystalline metals, such as bismuth and antimony. At a pressure of 6000 atmospheres finely powdered bismuth unites

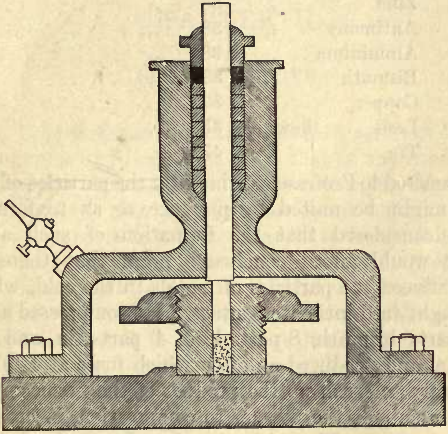

Fig. 4.

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[1] *Bul. de l'Acad. de Belgique* (2), tom. xlv. No. 6, 1878; (2) tom. xlix. No. 5, 1880.

into a solid mass, having a crystalline fracture. Tin when similarly compressed in powder, is made to flow through a hole in the base forming a wire. The following table shows the amount of compression required to unite the powders of the respective metals :—

Lead	unites at	13	tons	per square inch.
Tin	,,	19	,,	,,
Zinc	,,	38	,,	,,
Antimony	,,	38	,,	,,
Aluminium	,,	38	,,	,,
Bismuth	,,	38	,,	,,
Copper	,,	33	,,	,,
Lead	flows at	33	,,	,,
Tin	,,	47	,,	,,

It occurred to Professor Spring that the particles of different metals might be united by pressure, so as to form alloys, and he considered that the formation of such alloys by pressure would afford conclusive proof that there is true union between the particles of metals in the cold, when they are brought into intimate contact. He compressed a mixture of 15 parts bismuth, 8 parts lead, 4 parts tin, and 3 parts cadmium, and produced an alloy which fuses at 100° C. It is necessary to crush up the product of the first compression, and again submit the powder to compression, in order to get a perfect alloy. The objection has been urged that the mixture may have been fused by the heat of compression. Professor Spring has experimentally proved that this was not the case. The compression was effected with extreme slowness, and he calculates that if all the work done in compressing the powders were translated into heat, it would only serve to heat a cylinder of iron 10 mm. in height and 8 mm. in diameter 40·64° C. Spring took the organic compound *phorone*, which melts at 28° C., and compressed it in precisely the same way as the metallic powders. Only imperfect union of the particles resulted, and the 28° of heat necessary to melt the phorone was not generated.[1]

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[1] *Bul. Soc. Chim.* Paris, 1884, tom. xli. p. 488.

CHAPTER II

COPPER ALLOYS

§ 21. Copper forms with other metals a series of alloys far more numerous and important than that of any other metal, which may be accounted for by its red colour, high malleability, ductility, toughness, softness, and tenacity; which properties it imparts in a great measure to many of its alloys, even when united with metals opposite to it in character, such as zinc. Next to iron, it may be considered the most useful of all the metals both from its valuable properties when used alone, and its intrinsic value as a constituent of alloys. The very properties which make copper so useful are sometimes a disadvantage for certain purposes; for instance, the toughness and closeness of grain make it more difficult to turn in a lathe than brass; and its softness makes it unfit to be used alone for objects subjected to great wear and tear. In the vast majority of cases in which copper is used it has to be melted and cast into moulds of various kinds, in order to prepare it for further treatment, and the difficulties in producing sound castings are so great, that it can only be successfully manipulated in the hands of a very skilful and experienced workman; even then a common practice is to add some other substance, so that it is probably not too much to say that pure copper has never been cast in considerable quantity, so as to produce a good ductile casting free from blow-holes. Great attention has been directed to this subject of late years in consequence of the demand for solid-drawn copper tubes, rollers, etc.; and different physics have been added to the copper in melting, with a view of overcoming the inherent defects.

It must be borne in mind that pure copper is not a commercial article, and although copper is now manufactured on the large scale in a purer state than previously, the metal retains ingredients which modify the valuable properties the metal possesses in its chemically pure state. The common impurities are iron, arsenic, antimony, and sometimes sulphur. These elements even in very small quantities seriously affect copper, but they may be neutralised to some extent by uniting them with oxygen. When such metal is melted in contact with air, some of the copper is oxidised, forming cuprous oxide Cu_2O, which makes the whole mass brittle and unworkable; some air or carbonic oxide is also retained in the gaseous state, and on the metal solidifying at the surface some of this gas will be enclosed in the interior of the mass, and produce a honeycombed structure. To prevent access of air, the metals may be covered with charcoal, and this when used judiciously may be effective, but the great difficulty is to know when the carbon has done its work. Carbon in contact with air will produce carbonic oxide, and this gas probably penetrates the copper to some extent and removes the oxygen, but if any further excess of carbonic oxide is admitted, it may reduce the oxides present as impurities, as well as oxide of copper, and the elements being liberated, will alloy with the copper, making it brittle and analogous in properties to what is technically known as "overpoled" copper. Seeing then that commercial copper is impure, but that the impurities may be neutralised to a great extent by oxygen, the problem is to discover the point when this end has been attained, without introducing an excess of air. On the other hand, it may be as efficacious, and much more easy, to admit an excess of oxygen, and subsequently remove it, by adding some body which has a stronger affinity for oxygen than copper has. To this end Mr. Walton, of the Ansonia copper works of the United States of America, has patented a process of preparing copper for casting, which, in the words of the patentee, is as follows:—

"My present invention is for treating copper in crucibles, so as to exclude the action of the atmosphere, and subject the copper to the action of carbon sufficiently to remove the oxygen, and render such copper solid when cast, and increase its malleability and ductility. I take eight pounds of zinc, either in the form of an oxide or carbonate, and mix it with one bushel of ground charcoal, wet it, and make it into a stiff paste, portion it out into, say twenty-four parts, make it into rough balls, and dry at a moderate heat. The copper is placed in a crucible in a furnace, and when on the point of melting, one of the balls is dropped upon the copper, and gradually falls in pieces and covers the copper as it melts down, thereby entirely excluding the atmosphere from the surface of the copper; at the same time the zinc in the mass is evolved, and dispels any oxygen which may remain in the crucible. It may be supposed that the oxide of zinc will impregnate the copper, but such is not the case; the charcoal coming in contact with the copper, and oxide of zinc being volatile under the action of heat,[1] no combination with the copper takes place, and the zinc is volatilised and carried off through the flue, while the charcoal remains on the surface of the copper, and combines with any excess of oxygen and burns. Copper treated in this way becomes perfectly malleable, and is thoroughly toughened, and is, in fact, improved by this treatment. My improvement is especially available when the copper is melted in a crucible, but it may be used when melted on a hearth or otherwise. The impurities of common copper are thrown to the surface in a slag, and the copper made so that it will work better either hot or cold, and stand a greater test for either tension or ductility.

"The above method of treatment can be applied to copper that is to be used in the manufacture of any article. Copper so treated will remain in a very liquid state much longer than that treated in the ordinary manner, and the copper can be brought to a very great heat without losing its toughness. When casting such articles as tubes, or small or thin castings, a little phosphorus, added just before pouring, assists very materially in keeping the metal in a liquid state; and also prevents the absorption of oxygen from the atmosphere while cooling in the moulds."

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[1] Zinc oxide is practically non-volatile. See Percy's *Metallurgy*, p. 532.

§ 22. In addition to the statements already made concerning impurities in copper, the following summary of the effects of different elements will doubtless be of use to those interested in the manufacture of its alloys.

Phosphorus.—A small quantity does not sensibly alter the colour of copper, but a large quantity renders it gray. One half per cent makes it very hot-short, and only capable of being rolled in the cold, without cracking. A little phosphorus added to molten copper in a crucible promotes soundness in the subsequent casting. Phosphorus increases the fusibility and hardness of copper, and when present in quantity, renders it brittle at the ordinary temperature. Copper containing 11 per cent of phosphorus is extremely hard, of a steel-gray colour, is susceptible of a fine polish, but readily tarnishes. In making phosphorised copper, by adding phosphorus direct, the metal should not be stirred with an iron rod, as phosphorised iron will also be formed, and alloy with the copper.

Silicon.—Copper is contaminated with silicon when strongly heated in contact with sand and carbon. Copper containing 2 per cent of silicon resembles gun-metal in colour; is tough, harder than copper, red-short, but may be rolled in the cold. Mr. Anderson of Woolwich found copper containing 1·82 per cent of silicon tougher than gun-metal. If the temperature employed in heating the copper be too low, or not sufficiently prolonged, only a little silicon will be reduced, and the metal will resemble slightly under-poled copper.

Arsenic.—Copper and arsenic readily combine when metallic arsenic is dropped into molten copper. When a very small quantity is thus added, the metal may be cast into a sound ingot, which contracts during solidification like phosphorised copper, and may be rolled cold, and afterwards drawn into fine wire. Much arsenic is highly injurious, making the metal hard and brittle. Arsenic also readily combines with copper when one of its compounds is heated with charcoal in contact with copper.

Iron.—The malleability of copper is seriously impaired by the presence of iron, which renders the copper harder, paler in colour, more infusible, and brittle. It may, however, be removed by the use of an oxidising flux.

Lead.—One half per cent of lead in copper makes it both hot- and cold-short, and can only be removed by causing some of the copper to pass into the slag. In quantities less than this, lead is sometimes added to copper intended for rolling.

Antimony renders copper hard and brittle, and imparts to the fractured surface a dull yellowish-gray colour. It is more injurious than arsenic.

Bismuth.—This metal is stated to exert a specially injurious influence on copper, a very small quantity makes it hot-short, and $\frac{1}{200}$ makes it sensibly cold-short.

Zinc in very small quantity does not much alter the character of copper; it tends to impart a yellow colour and fibrous fracture. $\frac{6}{1000}$ of zinc in copper makes the latter hot-short but not cold-short.

Nickel and Cobalt occasionally occur in copper ores, and are reduced along with the copper. These metals make copper less malleable, especially in the presence of a little antimony. The metal is then harder and paler in colour.

Tin in very small quantity does not appear to affect the working properties of copper except to make it a little harder.

The foregoing remarks concerning the effect of small quantities of foreign metals on the properties of copper do not apply in the same degree when metals are added to copper in considerable quantities to form what is generally understood by the term "alloys." For example, one per cent of zinc in copper will make it hard and red-short, but 20 per cent of zinc alloyed with 80 per cent copper will produce an exceedingly malleable alloy. Alloys of copper will be considered as those alloys in which copper is the principal constituent, and not those in which copper plays a subordinate part. Thus standard silver and standard gold contain copper, and these are not termed copper alloys, but silver and gold alloys respectively. The chief alloys of copper are: brass, bronze, and German silver, and these are the alloys most extensively used in the various industries.

BRASS

§ 23. The term brass will be used in this work to signify all alloys of which copper and zinc are the essential and chief constituents; but it is generally limited in the industrial arts to those alloys which are decidedly yellow, or have the yellowish tint characteristic of common brass. Alloys of zinc and copper are known in commerce by a variety of names, and indeed, great confusion has been introduced by the multiplication of empirical names to represent one and the same substance. This is doubtless owing to the ignorance that formerly prevailed, when every mixture was jealously guarded as a great secret, and fanciful names given to hide the real composition. Moreover, some alloys have been handed down to us from very early times, and their names corrupted so as to have different appellations in different localities. Dr. Percy mentions "that the terms *tombac*, *prince's metal*, *similor*, and *Mannheim gold* are used by some authors to designate alloys consisting of about 85 per cent copper and 15 per cent zinc; whereas, according to others, *prince's metal* and *Mannheim gold* are synonymous, and are composed of 75 per cent copper and 25 per cent zinc; according to another author, *similor* consists of about 71½ per cent copper and 28½ per cent zinc; and *Mannheim gold* of 80 per cent copper and 20 per cent zinc; and again, according to another author, *similor* and *Mannheim gold* are synonymous, and are applied to alloys of copper containing from 10 to 12 per cent zinc and from 6 to 8 per cent tin."[1]

That brass was known to the ancients is beyond dispute, but its direct preparation from copper and zinc is an invention of more modern times. Mines containing the ores from which yellow metal was produced were highly esteemed, and much regret was expressed when the ores were exhausted. In process of time it was observed that a certain ore (probably calamine $ZnCO_3$), when smelted in contact with copper, produced a metal of a yellow colour, and this process long continued to be used for making brass, without it becoming known what metal the ore contained, and what imparted the change of properties to the copper. The preparation of brass, by direct mixing of the two metals, copper and zinc, was probably practised soon after the metal zinc was first isolated. In 1743 it is stated that zinc works were established at Bristol, and in 1758 a patent was granted to Mr. Champion of Bristol for making "spelter" and brass, but the brass was still made by the indirect process from calamine $ZnCO_3$, or calcined blende ZnO. Hutton states that the brass industry was introduced into Birmingham about 1740 A.D. by the family of Turner, and that the chief supply of the metal was derived from the Macclesfield, Cheadle, and Bristol companies.

Commercial brass never consists entirely of copper and zinc, since whatever impurities exist in the separate metals will also be found in the alloy, though probably in smaller quantity, the most common of these being lead, tin, iron, and arsenic. It often happens that some of these are purposely added, to produce a given effect in the alloys. The colour of brass shows great variations, according to the proportions of the constituents, ranging from the red of copper at one end, to the bluish-white of zinc at the other. But the change from red to white is not so uniform as a casual observer might suppose. Thus alloys containing 94 to 99 per cent copper are red, with only a faint yellow tint; with 87 to 93 per cent copper, the colour is reddish-yellow; from 79 to 86 per cent copper, a yellowish-red tint prevails; below this, down to 74 per cent copper, the alloys are yellow, with a content of 67½ per cent copper, a reddish-yellow tint is obtained; with 60 to 66 per cent copper the colour is a full yellow; with 59 per cent copper, a reddish colour is obtained; with 52 per cent copper the colour is nearly golden-yellow; with a less quantity of copper than the above, the colour of the zinc begins to overpower the red colour of the copper, the alloys becoming more lead-like in appearance as the proportion of zinc increases.

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[1] Percy's *Metallurgy*, p. 606.

Copper and zinc may be united in all proportions, forming homogeneous alloys; and the combination is usually attended with evolution of heat. Certain varieties of brass are exceedingly malleable and ductile, and these properties, combined with the variety of shades of colour obtained by suitable mixing, and the moderate cost, render copper-zinc alloys most valuable for ornamental purposes. Brass possesses all the necessary advantages as a constructive material for works of art, and with the aid of transparent varnishes, termed lacquers, which have been brought to great perfection, it resists the action of the atmosphere remarkably well. The malleability of brass varies with the composition, with the temperature, and with the presence of foreign metals, which are sometimes in minute quantities. Some varieties are only malleable when rolled hot, others can be rolled at any temperature. Alloys containing up to 35 per cent zinc can be drawn into wire, but those containing 15 to 20 per cent of zinc are the most ductile. The alloy known as Dutch metal, which is an alloy of copper and zinc, containing more copper than ordinary brass, is an example of the great malleability of certain kinds of brass. The thickness of the leaves of Dutch metal is said not to exceed $\frac{1}{52900}$ of an inch.

Brass is harder than copper, and therefore better adapted to resist wear and tear. It acts well under the influence of a percussive force, as in the process of stamping, provided it is suitably annealed at proper intervals, in order to counteract the effects of local hardening, due to the compression of the particles into what may be termed unnatural positions. During the ordinary process of annealing the metal becomes coated with a scale of oxide, by union with the oxygen of the air, which oxide requires to be removed at each stage. This is done by dipping the metal in aquafortis, or dilute sulphuric acid, then scouring with sand if necessary, and finally well rinsing in water.

The melting point of brass is less than the mean of the melting points of its constituents, and this moderate melting point is of the utmost importance in the case of remelting, for casting or other purposes. The melting point of zinc is very much below that of copper, and when an alloy of these metals is strongly heated, the zinc volatilises, while the copper remains for the most part fixed, so that the loss of zinc will be considerable if the temperature is raised too high, and the operation of melting unduly prolonged; moreover, the affinity of zinc for oxygen is far greater than that of copper, and if air is freely admitted a considerable portion of the zinc will be oxidised, so that the metal should be excluded from the air as much as possible, by covering it with a layer of charcoal, or other substance, which has no chemical action upon the metal. The easy fusibility of brass, and its fluidity when melted, render it valuable for casting, as it is capable of receiving very fine impressions from the mould. Cast brass is generally more or less crystalline, which is very pronounced in the brittle varieties.

The formation of copper-zinc alloys is generally attended with contraction, which attains its maximum in the alloys Cu_2Zn_3 and $CuZn_2$, containing 39·2 and 32·6 per cent of copper respectively. These alloys are brittle, and exhibit none of the characteristic properties of the constituent metals. The density of brass is increased by mechanical treatment, but this effect is partly annulled by sudden, and still more by slow cooling.[1]

In mixing brass for casting, old copper from worn-out articles, scrap brass, etc., are frequently used, and as these often contain injurious ingredients, which modify the properties of the alloy, great care should be exercised in the selection. For some kinds of casting this is not important, but when the metal is required for rolling into sheet, or drawing into wire, or for making the best kinds of brass tubing, the use of impure metal is often fatal, entailing a considerable amount of expense on account of waste, and much annoyance to those concerned. The most common impurities, as already stated, are lead, tin, iron, and arsenic, all of which harden the metal and tend to make it brittle. For brass intended for filing and turning, 1 to 2 per cent of lead is added, in order to prevent the unpleasant fouling of the tools in working. Brass containing lead should be very thoroughly mixed before pouring, and the cast metal should be cooled as quickly as is expedient, otherwise the lead separates out in the lower portion of the casting, producing unsightly spots. A little tin is often an advantage in brass; it renders the metal more easily fusible, less brittle, somewhat sounder, and enables it to take a better polish. A little iron considerably increases the hardness of brass, lightens the colour, and such metal is more easily tarnished by the atmosphere than brass free from iron.

When an ingot of ordinary brass is broken while hot, its fracture is coarsely fibrous, but when broken while cold, it should be finely granular. When the fracture of a cast ingot of certain metals is fibrous, the directions of the fibres will be at right angles to the cooling surface. In the case of a sphere, the fibres will have the direction of radii; and in the case of a square, two diagonals will be plainly visible on the transverse fracture, formed by the points of junction of the internal extremities of the fibres.[2] Mr. F. H. Storer[3] states "that the tendency to shoot into fibres extends from alloys containing 57 or 58 per cent of copper down to those containing 43 to 44 per cent, where it gradually disappears. The inclination to form fibres is strongest in those alloys which contain nearly equal atomic proportions of copper and zinc, being less clearly marked as one recedes in either direction from this point, until a stringy texture, analogous to that of copper, is reached on one hand, and the peculiar pastiness of zinc on the other. In preparing crystals, this pastiness manifests itself decidedly in the alloys immediately below those which are fibrous, becoming more strongly marked as the alloys are richer in zinc. The fracture of these white alloys is for the most part vitreous or glassy."

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[1] Riche, *Ann. Chim. Phys.* (4), xxx.

[2] Percy's *Metallurgy*, p. 608.

[3] *Mem. of Amer. Acad.* 1860 (8), p. 35.

Brass is occasionally obtained in crystals. Storer prepared the most perfect individual crystals from brasier's solder, which consists of equal parts by weight, of copper and zinc, and occurs in the state of coarse powder, produced by heating the alloy to a sufficient degree and pounding it in a mortar while hot. The alloy containing 5 to 6 per cent of zinc was found to crystallise remarkably well. It will be seen from the above remarks that the crystalline condition of copper-zinc alloys does not depend on an excess of zinc, as might be presupposed from the highly crystalline character of zinc. As before stated, zinc becomes malleable when worked at a temperature of from 100° to 150° C., but at higher temperatures it again becomes brittle. It is assumed that the brittleness is intimately connected with the crystalline condition. Kalischer examined different varieties of sheet brass having the following composition:—

	I	II	III	IV
Copper . . .	66	62·5	60	56·8
Zinc . . .	34	37·5	40	43·2
	100	100·0	100	100·0

Nos. I and II were crystalline, No. III showed traces of crystallisation, and No. IV did not become crystalline even by heating.

	I	III	IV
Copper . . .	73·74	80·38	90·09
Zinc . . .	25·96	19·29	9·91
Tin . . .	·30	·33	...
	100·00	100·00	100·00

The above three specimens were all crystalline.

	I	II
Copper	90	88·23
Zinc	5	8·82
Tin	5	2·95
	100	100·00

In the above specimens no crystallisation could be detected.

The tensile strength of copper-zinc alloys is widely divergent; the greatest strength, according to Mallet, is obtained in the alloy containing 32·85 per cent copper, but this is very probably a mistake, and the greatest tenacity is in alloys containing upwards of 50 per cent copper.

§ 24. The following table of the composition and properties of copper-zinc alloys is taken from Mr. Mallet's table and Karsten's observations[1] :—

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[1] Percy's *Metallurgy*, p. 611.

No.	Atomic constitution.	Composition per cent.	Specific gravity.	Colour.	Order of Intensity.	Fracture.	Tensile strength in tons per square inch.
1	Cu	100	8·667	..	..	..	24·6
2	10 Cu+Zn	90·7 +9·3	8·605	Reddish-yellow .	1	C.C.	12·1
3	9 Cu+Zn	89·8 +10·2	8·607	,, .	2	F.C.	11·5
4	8 Cu+Zn	88·6 +11·4	8·633	,, .	3	F.C.	12·8
5	7 Cu+Zn	87·3 +12·7	8·587	,, .	4	F.C.	13·2
6	..	86·3 +13·7	8·705	..	..	..	..
7	6 Cu+Zn	85·4 +14·6	8·591	Yellowish-red .	3	F.F.	14·1
8	..	84·0 +16·0	8·639	..	..	..	..
9	5 Cu+Zn	83·02+16·98	8·415	Yellowish-red .	2	F.C.	13·7
10	..	80·6 +19·4	8·679	,, .	..	..	..
11	4 Cu+Zn	79·65+20·35	8·448	,, .	1	F.C.	14·7
12	..	75·9 +24·1	8·609	Brass-yellow .	..	..	..
13	3 Cu+Zn	74·58+25·42	8·397	Pale yellow .	..	F.C.	13·1
14	..	73·8 +26·2	8·582	Brass-yellow .	..	..	..
15	..	67·5 +32·3	8·499	Reddish brass-yellow	..	..	..
16	2 Cu+Zn	66·18+33·82	8·299	Full yellow .	1	F.C.	12·5
17	..	60·0 +40·0	..	Yellow . .	..	..	..
18	..	59·0 +41·0	8·375	Reddish-yellow .	..	..	..
19	..	52·0 +48·0	8·229	Nearly gold-yellow	..	..	..
20	Cu+Zn	49·47+50·53	8·230	Full yellow .	2	C.C.	9·2
21	..	46·5 +53·5	..	Reddish-white .	..	..	..
22	..	44·0 +56·0	..	White, but viewed obliquely deep yellow	..	..	..
23	..	35·5 +64·5	..	Bluish-white .	..	..	..
24	Cu+2 Zn	32·85+67·15	8·283	Deep yellow? .	..	C.C.	19·3?
25	8 Cu+17 Zn	31·52+68·48	7·721	Silver-white? .	1	C.	2·1
26	8 Cu+18 Zn	30·30+69·7	7·836	,,	1	V.C.	2·2
27	8 Cu+19 Zn	29·17+70·83	8·019	Silver-gray. .	3	C.	0·7
28	8 Cu+20 Zn	28·12+71·88	7·603	Ash-gray . .	3	V.	3·2
29	8 Cu+21 Zn	27·10+72·90	8·058	Silver-gray. .	2	C.	0·9
30	8 Cu+22 Zn	26·24+73·76	7·882	,,	1	C.	0·8
31	8 Cu+23 Zn	25·39+74·61	7·443	Ash-gray . .	4	F.C.	5·9
32	..	24·8 +75·2	..	Bright lead-gray	..	..	..
33	Cu+3 Zn	24·50+75·50	7·449	Ash-gray . .	1	F.C.	3·1
34	..	21·0 +79·0	..	Bright lead-gray	..	..	..
35	Cu+4 Zn	19·65+80·35	7·371	Ash-gray . .	2	F.C.	1·9
36	Cu+5 Zn	16·36+83·64	6·605	Very dark gray .	..	F.C.	1·8
37	..	14·7 +85·3	..	Bright lead-gray	..	..	..
38	..	11·25+88·75	..	..	..	..	..
39	..	9·5 +90·5	..	Dark lead-gray .	..	..	..
40	Zn	100	6·895	..	..	..	15·2

"**Remarks on the preceding Table.**—The figures in column 6 represent intensity of tint of the same colour. In column 7 the letters are abbreviations for the characters of the fractures according to Mallet's nomenclature, thus F.F.

fine-fibrous, C. conchoidal, V.C. vitreous-conchoidal, F.C. fine-crystalline, C.C. coarse-crystalline. The tensile strength was determined on prisms $\frac{1}{4}$ inch square, without having been hammered or compressed after being cast; and the weights given are those which each prism just sustained for a few seconds before disruption.

"6. Approaching *tombac* in colour, is not quite so good for rolling, hammering, or wire drawing as common red brass, which contains less copper in proportion to the zinc.

"8. Comes very near 'red-brass,' which it quite equals with respect to its working qualities.

"10. The reddish colour is now beginning to pass into brass-yellow; it behaves itself irreproachably under the rolls and hammer, and in wire drawing.

"13. Working qualities quite the same as those of common brass. Karsten remarks that it was this alloy which was puffed for some time in England under the name of Mosaic gold.

"14. In working qualities not different from common brass.

"16. It contains 4 per cent more zinc and 4 per cent less copper than common brass. The colour is no longer pure brass-yellow, but has a reddish tint, works excellently under the rolls and hammer, as well as in wire drawing.

"19. Much to be recommended, on account of its golden colour, and though it possesses greater tenacity than the preceding, and less hardness, is brittle. Well adapted for cast ware. Very flexible after casting while still hot. When cold it is hard to cut, and is rather fractured than cut. The ingots after being cut, annealed, and cooled, can no longer be rolled. If, after heating and cooling to the temperature of boiling water, they are rolled, they produce only very brittle, fragile sheets, much cracked at the edges, notwithstanding that frequent annealing during rolling may have been resorted to; it is quite unsuitable for rolling, hammering, or wire drawing.

"20. Very flexible while strongly heated. Rolls tolerably well cold, though it frequently cracks at the edges. During rolling into thin sheets, it requires more frequent annealing than common brass. It cannot be soldered, as it melts at the same temperature as the solder. It is not adapted for wire drawing.

"21. Fracture reticulated. Possesses a tolerable degree of tenacity, but by hammering becomes so brittle that at no temperature can it be sufficiently drawn out for practical purposes.

"22. The lustre is so imperfectly metallic, that it would hardly be recognised as a metallic alloy. Its great brittleness and frangibility, combined with its perfectly conchoidal and smooth fracture, communicate to the alloy more the appearance of a sulphur compound than that of a mixture of two metals.

"23. More brittle than the last; fracture smooth, even, small-conchoidal; lustre strongly metallic.

"25, 26, 27. Very brittle. Too hard to file or turn; lustre nearly equal to that of speculum metal.

"28, 29. Brittle. Too hard to file or turn; lustre nearly equal to that of speculum metal.

"30. Very brittle. Too hard to file or turn; lustre nearly equal to that of speculum metal.

"31. Barely malleable.

"32. Brittle; fracture granular, uneven; has a tolerable degree of tenacity, but cannot be worked under the rolls or hammer.

"33. Brittle.

"34. In external character and working qualities closely resembles No. 32.

"36. Brittle.

"38. Fracture finely granular.

"39. Has sufficient tenacity to admit of being somewhat extended under the rolls and hammer, if, after annealing, it is not allowed to become cold."

§ 25. PROPERTIES OF COPPER-ZINC ALLOYS COLLATED FOR THE COMMITTEE ON ALLOYS APPOINTED BY THE UNITED STATES BOARD (*Report*, vol. ii. 1881)

No.	Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity.	Colour.	Fracture.	Tenacity in pounds per sq. inch.	Order of ductility (Mallet)	Relative ductility (Thurston).	Order of malleability (Mallet)	Hardness (Mallet and Calvert and Johnson).	Order of fusibility (Mallet)	Conductivity for heat. Silver =100.	Conductivity for electricity. Silver =100.	Authority.	Remarks.
		Cu.	Zn.	Cu.	Zn.													
1	..	100	0	..	..	8·874	red	fibrous	27,800	8	30·8	..	..	..	..	..	U.S.B.	..
2	..	100	0	..	..	8·667	tile-red	earthy	55,104	..	..	1	22	15	..	..	Ml.	..
3	..	100	0	..	..	8·921	..	..	..	..	..	..	..	..	..	93·16	Ma.	..
4	..	100	0	..	..	..	..	..	..	..	..	..	30·1	..	81·1	..	C. J.	..
5	..	100	0	..	..	8·952	..	..	..	..	..	..	..	..	..	..	Mar.	Sheet copper.
6	..	100	0	..	..	..	..	..	..	..	..	..	..	..	73·6	79·3	We.	..
7	..	100	0	..	..	8·672	..	..	24,252	..	..	..	..	..	..	..	We.	Mean of 9 samples.
8	..	99·15	0·85	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Tombac for buttons.
9	..	97·8	2·2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	Red tombac of Vienna.
10	..	97·5	2·5	97·83	1·88	8·791	yellow-red	vesicular	27,240	..	118·9	..	..	..	..	..	U.S.B.	..
11	..	97·2	2·5	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Railway axles, porous.
12	..	95	5	96·07	3·79	8·825	yellow-red	vesicular	11,500	..	37·9	..	..	..	..	..	U.S.B.	Defective bar.
13	..	93·6	6·4	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Pinchbeck.
14	..	92·5	7·5	92·32	7·68	8·746	yel.-red	vesicular	..	..	..	..	..	..	..	..	U.S.B.	..
15	..	92·5	7·5	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Bearings, Austria.
16	..	92	8	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Red tombac of Paris.
17	..	91	9	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Tombac.
18	$Cu_{10}Zn$	90·72	9·28	..	..	8·605	red-yellow	coarsely crystalline	27,104	6	..	13	21	14	..	..	Ml.	..

19	$Cu_{10}Zn$	90·65	9·35	..	9·60	8·534	..	..	..	..	..	..	..	..	..	..	Ml.	Specific gravity of ingot 8·753.
20	..	90	10	90·56	9·42	8·773	yellow-red	vesicular	..	..	169·1	..	..	..	..	..	U.S.B.	..
21	..	90	10	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	French oréide.
22	Cu_9Zn	89·8	10·2	..	..	8·607	red-yellow	finely crystalline	25,760	4	..	11	20	13	..	..	Ml.	..
23	..	88·89	11·11	..	..	..	..	..	..	..	..	..	..	..	27·3	25·5	We.	..
24	Cu_8Zn	88·6	11·4	..	..	8·633	red-yellow	finely crystalline	28,672	2	..	10	19	12	..	..	Ml.	..
25	..	87·5	12·5	88·94	10·97	..	yellow-red	vesicular	..	..	..	..	..	..	..	..	U.S.B.	..
26	Cu_7Zn	87·3	12·7	..	..	8·587	..	finely crystalline	29,568	9	..	9	18	11	..	..	Ml.	..
27	..	86·67	13·33	..	..	..	..	..	..	..	..	..	..	..	29·9	30·9	We.	..
28	..	86·38	13·61	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Very delicate castings.
29	..	86	14	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Ornaments of Hanover.
30	..	85·5	14·5	..	..	8·591	yellow-red	fine fibrous	31,584	5	..	8	17	10	..	..	Bo.	French oréide.
31	Cu_6Zn	85·34	14·66	..	..	8·71	..	..	..	..	..	..	..	..	..	..	Ml.	..
32	..	85·3	14·7	..	..	..	..	..	..	..	..	..	..	..	..	..	Ri.	Specific gravity of powder 8·584.
33	..	85	15	89·8	10·06	8·656	red-yellow	earthy	..	..	250·1	..	..	..	..	..	Bo.	Paris jewellery.
34	..	85	15	..	..	..	..	..	..	..	..	..	..	..	..	..	U.S.B.	..
35	..	84·6	15·4	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Tombac of Oker.
36	..	84·21	15·79	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Gold-leaf.
37	..	83·99	17·1	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Tombac for buttons.
38	Cu_5Zn	83·02	16·98	..	..	8·415	red-yellow	finely crystalline	30,688	11	..	2	16	9	..	..	Bo.	Bronze powder.
39	Cu_5Zn	82·95	17·05	..	..	8·673	..	..	..	..	..	..	427·08	..	71·5	..	Ml.	Bath metal.
40	..	82·54	17·46	..	..	..	..	..	..	..	..	..	..	..	..	..	C. J.	..
41	..	82·5	17·5	82·93	16·98	8·633	red-yellow	earthy	32,600	..	105·3	..	..	..	..	..	Bo.	Alloy for jewellery.
42	..	82·46	17·54	..	..	..	..	..	..	..	..	..	..	..	31·1	29·02	U.S.B.	..

PROPERTIES OF COPPER-ZINC ALLOYS—*Continued*

No.	Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity.	Colour.	Fracture.	Tenacity in pounds per sq. inch.	Order of ductility (Mallet)	Relative ductility (Thurston).	Order of malleability (Mallet)	Hardness (Mallet and Calvert and Johnson).	Order of fusibility (Mallet)	Conductivity for heat. Silver =100.	Conductivity for electricity. Silver =100.	Authority.	Remarks.
		Cu.	Zn.	Cu.	Zn.													
43	..	82·3	17·7	..	..	..	..	..	..	..	..	..	..	..	..	..	We.	..
44	..	80	20	81·91	17·9	8·598	yellow	earthy	32,670	..	113·1	..	..	..	..	..	Bo.	Ornaments.
45	Cu_4Zn	79·65	20·35	..	..	..	yellow-red	finely crystalline	52,928	7	..	3	15	8	..	..	U.S.B.	..
46	Cu_4Zn	79·56	20·44	..	..	8·650	..	..	..	..	..	..	468·75	..	66·6	..	Ml.	Dutch metal.
47	Cu_4Zn	79·51	20·49	..	21·8	8·638	..	..	..	..	..	..	..	..	..	..	C. J.	..
48	..	77·9	22·1	..	..	..	..	..	..	..	..	..	..	..	..	..	Ri.	Specific gravity of powder 8·367.
49	..	77·5	22·5	77·39	22·45	8·574	yellow	earthy	35,630	..	97·5	..	..	..	..	..	Bo.	Vienna gold-leaf.
50	..	75·7	24·3	..	..	..	..	..	..	..	..	..	..	..	..	..	U.S.B.	..
51	..	75	25	76·65	23·08	8·528	yellow	earthy	30,520	..	76·7	..	..	..	..	..	Bo.	Bristol metal.
52	..	74·62	25·38	..	..	..	..	..	..	..	..	..	..	..	..	..	U.S.B.	..
53	Cu_3Zn	74·58	25·42	..	..	8·397	pale yellow	finely crystalline	29,344	10	..	4	14	7	..	..	Ml.	Rolled sheet brass.
54	Cu_3Zn	74·48	25·52	..	..	8·576	..	..	..	..	..	..	468·75	..	63·8	..	C. J.	Brass of 32 copper and 12 of zinc.
55	..	72·73	27·27	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	..
56	..	72·5	27·5	73·2	26·47	8·465	yellow	earthy	31,580	..	88·7	..	..	..	..	..	U.S.B.	..
57	..	72	28	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Chrysorin.
58	..	71·5	28·5	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Tombac.
59	..	70·1	29·9	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Suitable for forging or leaf.
60	..	70	30	71·2	28·54	8·444	yellow	earthy	30,510	..	77·8	..	..	..	..	..	U.S.B.	..
61	..	67·74	32·26	..	..	..	..	..	..	..	..	..	..	..	25·8	25·4	We	..
62	..	67·54	32·46	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Suitable for forging.

64	..	67·2	32·8	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Bristol metal.
65	..	66·7	33·3	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Chrysorin.
66	..	66·6	33·4	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Common brass.
67	Cu_2Zn	66·18	33·82	..	..	8·299	full yellow	finely crystalline	28,000	3	..	6	13	6	..	..	Ml.	..
68	Cu_2Zn	66·16	33·84	..	..	8·392	..	..	..	..	..	..	..	..	..	..	Cr.	..
69	Cu_2Zn	66·06	33·94	..	..	8·488	..	..	..	472·92	..	..	..	..	62·1	..	C. J.	..
70	..	66	34	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Suitable for forging.
71	..	65·98	34·02	..	34·5	8·41	..	..	..	..	..	..	..	..	..	..	Ri.	Specific gravity of powder 8·39.
72	..	65·4	34·6	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Good brass wire.
73	..	65·3	34·7	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Mosaic gold.
74	..	65	35	66·27	33·5	8·371	red-yellow	earthy	37,800	..	72·8	..	..	..	..	..	U.S.B.	..
75	..	65	34·76	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Suitable for forging.
76	..	63·5	36·5	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Suitable for forging.
77	..	62·5	37·5	63·44	36·36	8·411	red-yellow	earthy	48,300	..	60·6	..	..	..	..	..	U.S.B.	..
78	..	61·25	38·75	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Strong solder for brass.
79	..	60·8	39·2	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Bristol metal.
80	..	60·16	39·71	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Suitable for forging.
81	..	60	40	60·94	38·65	8·405	red-yellow	earthy	41,065	..	49	..	..	..	..	..	U.S.B.	..
82	..	60	40	..	..	..	..	..	..	..	..	..	..	..	..	..	..	Muntz' metal.
83	..	59·5	40·5	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Shipsheathing
84	Cu_3Zn_2	59·36	40·64	..	..	8·224	..	..	..	..	..	..	..	..	..	..	Cr.	..
85	Cu_3Zn_2	59·26	40·74	..	40·10	8·412	..	..	..	..	..	..	..	..	..	..	Ri.	Specific gravity of powder 8·239.
86	..	58·33	41·77	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Suitable for forging.
87	..	57·5	42·5	58·49	41·10	8·363	red-yellow	earthy	50,450	..	12·1	..	..	..	..	..	U.S.B.	..
88	..	55	45	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Bath metal.

No.	Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity.	Colour.	Fracture.	Tenacity in pounds per sq. inch.	Order of ductility (Mallet)	Relative ductility (Thurston).	Order of malleability (Mallet)	Hardness (Mallet and Calvert and Johnson).	Order of fusibility (Mallet)	Conductivity for heat. Silver =100.	Conductivity for electricity. Silver =100.	Authority.	Remarks.
		Cu.	Zn.	Cu.	Zn.													
89	..	55	45	55·15	44·44	8·283	red-yellow	earthy	44,280	..	19·5	..	..	..	..	..	U.S.B.	..
90	..	54·9	45·1	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Very ductile.
91	..	54	46	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	"
92	..	52·5	47·5	54·86	44·78	8·301	red-yellow	coarsely granular	46,400	..	7·4	..	..	..	..	..	U.S.B.	..
93	..	50	50	49·66	50·14	8·291	red-yellow	coarsely granular	30,990	..	3·1	..	..	..	..	..	U.S.B.	..
94	CuZn	49·47	50·53	..	..	8·230	full-yellow	coarsely crystalline	20,608	12	..	5	12	6	..	..	Ml.	German brass.
95	CuZn	49·32	50·68	..	..	7·808	..	..	..	..	..	..	604·17	..	68·8	..	C. J.	..
96	CuZn	49·23	50·76	..	50·30	8·304	..	..	..	..	..	..	..	..	..	..	Ri.	Specific gravity of ingot 8·263.
97	..	47·5	52·5	48·95	50·82	8·216	pinkish-gray	coarsely granular	26,050	..	·36	..	..	..	..	..	U.S.B.	..
98	..	45	55	47·56	52·28	..	pinkish-gray	coarsely granular	24,150	..	·26	..	..	..	..	..	U.S.B.	..
99	..	43	57	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Escutcheons of locks.
100	..	42·5	57·5	43·36	56·22	8·035	pinkish-gray	finely granular	9,710	..	·02	..	..	..	..	..	U.S.B.	..
101	..	40	60	41·3	58·12	8·061	silver-white	vitreous conchoidal	3,727	..	·01	..	..	..	..	..	U.S.B.	..
102	Cu_2Zn_3	39·27	60·73	..	60·35	8·171	..	..	..	..	..	..	.	..	..	..	Ri.	Specific gravity of ingot 8·039.
103	..	37·5	62·5	38·36	61·05	7·982	silver-white	vitreous con-	3,087	..	·02	.	.	.	..	..	U.S.B.	..

104	Cu_3Zn_5	36·88	63·12	..	..	7·939	..	..	..	..	..	..	..	..	..	..	Cr.	..
105	..	35	65	36·62	62·78	7·974	silver-white	vitreous conchoidal	2,656	..	·006	..	..	..	..	..	U.S.B.	..
106	$CuZn_2$	33·34	66·66	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Strong solder for brass.
107	$CuZn_2$	32·85	67·15	..	..	8·283	deep yellow	coarsely crystalline	43,232?	1	..	7	10	6	..	..	Ml.	Watchmakers' brass?
108	$CuZn_2$	32·74	67·26	..	..	7·859	..	..	..	..	..	..	broke	..	42·8	..	C. J.	
109	$CuZn_2$	32·66	67·34	..	64·8	8·048	..	..	..	..	..	..	..	..	..	..	Ri.	Specific gravity of ingot 7·796.
110	..	32·5	67·5	35·68	63·71	7·966	silver-white	vitreous conchoidal	2,397	..	·11	..	..	..	..	..	U.S.B.	..
111	Cu_8Zn_{17}	31·52	68·48	..	..	7·721	silver-white	conchoidal	4,704	0	..	22	5	5	..	..	Ml.	Very brittle.
112	Cu_8Zn_{18}	30·3	69·7	..	..	7·836	silver-white	vitreous conchoidal	4,928	0	..	23	6	5	..	..	Ml.	,,
113	..	30	70	32·94	66·23	7·811	silver-white	vitreous conchoidal	1,774	..	·005	..	..	..	..	..	U.S.B.	..
114	Cu_8Zn_{19}	29·17	70·83	..	..	8·019	silver-gray	conchoidal	1,568	0	..	21	7	5	..	..	Ml.	Very brittle.
115	Cu_8Zn_{20}	28·12	71·88	..	..	7·603	ash-gray	vitreous	7,168	0	..	19	3	5	..	..	Ml.	Brittle.
116	..	27·5	72·5	29·2	70·8	7·766	light-gray	vitreous	6,414	..	·009	..	..	..	..	..	U.S.B.	..
117	Cu_8Zn_{21}	27·1	72·9	..	..	8·058	silver-gray	conchoidal	2,016	0	..	18	9	5	..	..	Ml.	Brittle.
118	Cu_8Zn_{22}	26·24	73·76	..	..	7·882	silver-gray	conchoidal	1,792	0	..	20	8	5	..	..	Ml.	Very brittle.
119	..	25·4	74·6	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Protect iron from rust.
120	Cu_8Zn_{23}	25·39	74·61	..	..	7·443	ash-gray	finely crystalline	13,216	0	..	15	1	5	..	..	Ml.	Barely malleable.
121	..	25	75	..	..	7·675	bluish-gray	finely granular	9,680	..	·002	..	..	..	..	..	U.S.B.	..
122	$CuZn_3$	24·64	75·36	..	..	7·736	..	..	..	..	..	..	broke	..	53·1	..	C. J.	..
123	$CuZn_3$	24·5	75·5	..	..	7·449	ash-gray	finely crystalline	11,424	0	..	16	2	4	..	..	Ml.	Brittle.

PROPERTIES OF COPPER-ZINC ALLOYS—*Continued*

No.	Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity.	Colour.	Fracture.	Tenacity in pounds per sq. inch.	Order of ductility (Mallet)	Relative ductility (Thurston.)	Order of malleability (Mallet)	Hardness (Mallet and Calvert and Johnson).	Order of fusibility (Mallet)	Conductivity for heat. Silver =100.	Conductivity for electricity. Silver =100.	Authority.	Remarks.
		Cu.	Zn.	Cu.	Zn.													
124	..	22·5	77·5	22·12	77·43	7·416	bluish-gray	finely granular	7,000	..	·004	..	..	..	..	..	U.S.B.	..
125	..	20	80	20·81	77·63	7·418	bluish-gray	finely granular	9,000	..	·002	..	..	..	..	..	U.S.B.	..
126	..	20	80	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Metal for buttons.
127	$CuZn_4$	19·65	80·35	..	..	7·371	ash-gray	finely crystalline	4,256	0	..	14	4	3	..	..	Ml.	White button metal.
128	$CuZn_4$	19·57	80·43	..	..	7·445	..	..	..	..	..	..	broke	..	58·9	..	C. J.	..
129	$CuZn_4$	19·52	80·48	..	79·3	7·863	..	..	..	..	..	..	..	..	..	..	Ri.	Specific gravity of ingot 7·215.
130	..	17·5	82·5	17·49	81·62	7·225	bluish-gray	finely granular	5,350	..	·003	..	..	..	..	..	U.S.B.	..
131	$CuZn_5$	16·36	83·64	..	..	6·605	very dark gray	finely crystalline	4,032	0	..	17	11	2	..	..	Ml.	Brittle.
132	$CuZn_5$	16·30	83·7	..	..	7·44	..	..	..	..	..	..	broke	..	59·5	..	C. J.	..
133		15	85	14·19	85·1	7·163	bluish-gray	finely granular	8,500	..	·004	..	..	..	..	..	U.S.B.	..
134	..	12·5	87·5	12·12	86·67	7·238	bluish-gray	finely granular	12,413	..	·009	..	..	..	..	..	U.S.B.	..
135	$CuZn_8$	10·82	89·18	..	89·9	7·315	..	..	..	..	..	..	..	..	..	..	Ri.	Specific gravity of ingot 7·299.
136	..	10	90	10·3	88·88	7·253	bluish-gray	finely granular	14,450	..	·1	..	..	..	..	..	U.S.B.	..
137	..	7·5	92·5	7·2	92·07	7·131	bluish-gray	finely granular	10,650	..	8·04	..	..	..	..	..	U.S.B.	..
138	..	5	95	4·35	94·59	7·108	bluish-	finely	18,065	..	·84	..	..	..	..	..	U.S.B.	..

139	..	2·5	97·5	2·45	97·43	7·08	bluish-gray	tabular crystalline	11,400	..	2·67	..	..	..	..	..	U.S.B.	..
140	..	0	100	..	..	7·143	bluish-white	tabular crystalline	5,400	..	26·51	..	..	..	..	..	U.S.B.	..
141	..	0	100	..	..	6·895	bluish-gray	tabular crystalline	34,048	..	..	12	23	1	..	..	Ml.	Brittle.
142	..	0	100	..	..	7·148	..	..	..	..	..	..	..	..	29·02	27·39	Ma.	..
143	..	0	100	..	..	..	..	..	..	..	..	..	..	..	62·8	..	C. J.	..
144	..	0	100	..	..	..	..	..	..	..	..	..	..	..	28·1	27·3	We.	..

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Cr.—Croockwit. *Erdmann's Journal*, vol. xlv. 1848, pp. 87-93.

C. J.—Calvert and Johnson. *Phil. Mag.* vol. xviii. 1850, pp. 354-359; *ibid.* vol. xvii. 1859, pp. 114-121; *ibid.* vol. xvi. 1858, pp. 381-383.

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Ml.—Mallet. *Phil. Mag.* vol. xxi. 1842, pp. 66-68.

Ri.—Riche. *Annales de Chimie*, vol. xxx. 1873, pp. 351-410.

U.S.B.—Report of Committee on Metallic Alloys appointed by United States Board. *Thurston's Investigations.*

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Professor R. H. Thurston, who conducted the investigations for the United States Board, makes the following remarks on the preceding table :—

"Alloys having the name of Bolley appended give compositions and commercial names, and mention valuable properties, such as are given in the column of remarks, but do not give results in figures as recorded by other authorities. The same properties and the same name are accorded by Bolley to alloys of different compositions, such as those which in the column of remarks are said to be suitable for forging. It might be supposed that such properties belonged to those mixtures, and not to other mixtures of similar composition. It seems probable, however, that when two alloys of different mixtures of copper and zinc are found to have the same strength, colour, fracture, and malleability, it will also be found that all alloys between these compositions will possess the same proportions, and hence, that instead of the particular alloys mentioned only being suitable for forging, all the alloys between the extreme compositions mentioned also possess that property.

"In the figures given from Mallet under the heads of order of ductility, order of malleability, hardness, and order of fusibility, the maximum of each of these properties is represented by 1.

"The figures given by Mallet for tenacity are confirmed by experiments of the author, with a few very marked exceptions. These exceptions are chiefly the figures for copper, for zinc, and for $CuZn_2$ (32·85 copper, 67·15 of zinc). The figures for $CuZn_2$, as given by Mallet, can, in the opinion of the author, only be explained on the supposition that the alloy tested was not $CuZn_2$, but another containing a per cent of copper, probably as high as 55. The figure for the specific gravity (8·283) given by Mallet indicates this to be the case, as does the colour. The figure for ductility would indicate even a higher per cent of copper. The name watchmaker's brass in the column of remarks must be an error, as that alloy is brittle, silver-white, and extremely weak.

"The figures of Calvert and Johnson and Riche, as well as those of the author, give a more regular curve than can be constructed from the figures of Mallet.

"The specific gravities in Riche's experiments were obtained both from the ingot and from powder. In some cases one, and in some cases the other, gave highest results. In the table under the head of specific gravity Riche's highest average figures are given, whether these are from the ingot or from the fine powder, as probably the most nearly correct. The figures by the other method, in each case, are given in the column of remarks. The figures of Riche and Calvert and Johnson are scarcely sufficient in number to show definitely the law regulating specific gravity to composition, and the curves from their figures vary considerably. The figures of the author being much more numerous than those of earlier experimenters, a much more regular curve is obtained, especially in that part of the series which includes the yellow or useful metals. The irregularity in that part of the curve which includes the bluish-gray metals is, no doubt, due to blowholes, as the specific gravities were in all cases determined from pieces of considerable size. If they were determined from powder, it is probable that a more regular set of observations could be obtained, and that these would show a higher figure than 7·143, obtained from cast-zinc. Matthiessen's figure for pure zinc (7·148) agrees very closely with that obtained by the author for the cast-zinc, which contained about 1 per cent of lead.

"The figures for hardness given by Calvert and Johnson were obtained by means of an indenting tool. The figures are on a scale in which the figure for cast-iron is taken as 1000. The alloys opposite which the word 'broke' appears were much harder than cast-iron; and the indenting tool broke them instead of making an indentation. The figures of alloys containing 17·05, 20·44, 25·52, and

33·94 per cent of zinc have nearly the same figures for hardness, varying only from 427·08 to 472·92. This corresponds with what has been stated in regard to the similarity in strength, colour, and other properties of alloys between these compositions."

§ 26. TABLE OF VARIOUS COPPER-ZINC ALLOYS

NAME.	Authority.	Copper.	Zinc.	Tin.	Lead.	Iron.
1. Brass, English .	Lavater .	70·29	29·26	·17	·28	...
2. ,, Heegermahl	,,	70·16	27·45	·79	·2	...
3. ,, Augsburg .	,,	70·89	27·63	·85	...	...
4. ,, Neustadt .	Kadernatsch	71·36	28·15	...	...	...
5. ,, Romilly .	Chaudet .	70·1	29·9	...	...	...
6. ,, unknown .	Karsten .	71·5	28·5	...	...	...
7. ,, ,, .	Regnault .	71·0	27·6	trace	1·3	...
8. ,, ,, .	Chaudet .	61·59	35·33	·25	2·86	...
9. ,, Stolberg .	,,	65·8	31·8	·25	2·15	...
10. Watch wheels .	Faisst .	60·66	36·88	1·35	...	·74
11. ,, ,, .	,,	66·06	31·46	1·43	...	·88
12. Ship nails, bad .	Percy .	52·73	41·18	...	4·72	...
13. ,, good .	,,	62·62	24·64	2·64	8·69	...
14. Tombac, English	Faisst .	86·38	13·61	...	...	trace
15. ,, German	Karsten .	84·0	15·5	...	...	...
16. Coin of Titus Claudius	Giraldin .	81·4	18·6	...	...	...
17. Coin of Titus, 79 A.D.	Phillips .	83·04	15·84	...	...	·5
18. Coin of Hadrian, 120 A.D.	,,	85·67	10·83	1·14	1·73	·74
19. Coin of Faustina jun., 165 A.D.	,,	79·15	6·67	4·97	9·18	·23
20. Antique bracelet, Naumberg	Goebel .	83·08	15·38	1·54	...	...
21. Statue of Louis XIV	D'Arcet .	91·40	5·53	1·7	1·37	...
22. Statue of Napoleon	,,	75	20	3	2	...
23. Brass for gilding	,,	82	15·5	2·5	...	...
24. ,, . . .	,,	64·5	32·5	2·5	...	...
25. ,, . . .	,,	82	15	3	...	...
26. ,, . . .	,,	78	20	2	...	...
27. Brass, colour pale yellow	König .	82·33	16·69	...	...	...
28. ,, deep yellow	,,	84·5	15·3	...	...	...
29. ,, red yellow .	,,	90	9·6	...	...	...
30. ,, orange .	,,	98·93	·73	...	...	...
31. ,, copper-red .	,,	99·9	...	...	...	·08
32. ,, violet .	,,	98·22	·5	trace	...	trace
33. ,, green .	,,	84·32	15·02	,,	...	·3

§ 27. SOME VARIETIES OF MODERN BRASS

Name.	Colour.	Copper.	Zinc.	Tin.	Lead.	Iron.	Gold.
Jeweller's gilding alloy	Red	94	6	...	...	...	...
,, ,,	,,	90·5	7·9	...	1·6	...	...
Pinchbeck	Reddish-yellow	88·8	11·2	...	...	...	...
,,	Red	93·6	6·4	...	...	...	...
Orëide (French gold)	Reddish-yellow	90	10	...	...	...	...
Talmi gold	Gold	90·70	8·33	...	...	...	·97
Tissier's metal with one per cent of arsenic	Red	97	2	...	...	...	...
Tournay's alloy	Yellow	82·54	17·46	...	...	...	...
Rich sheet-brass	,,	84	16	...	...	...	...
Bath metal, similor, etc.	,,	80	20	...	...	...	...
Dutch alloy	,,	76	24	...	...	...	...
Bristol sheet-brass	Bright yellow	72·8	27	...	·2	...	...
Brass wire	,,	70	30	...	...	...	...
Prince's metal	Yellow	75	25	...	...	...	...
Sheet and wire brass	Full-yellow	67	33	...	...	...	...
Mosaic gold, ordinary brass	,,	66·6	33·3	...	...	...	...
Bobierre's metal	,,	66	34	...	...	...	...
Muntz' metal	,,	62	38	...	...	...	...
,, ,,	,,	60	40	...	...	...	...
Gedge's metal	,,	60	38·5	...	...	1·5	...
Common brass	,,	64	36	...	...	...	...
Aich's metal	,,	60	38·2	...	...	1·8	...
French brass (Potin jaune)	Gray-yellow	71·9	24·9	1·2	2·0	...	...
Hamilton's metal, Chrysorin	Full-yellow	64·5	32·5	·3	2·7	...	...
French brass for fine castings	,,	71	24	2	3	...	...
Sterro metal	...	55·5	42	...	...	2·5	...
Hard solder for copper or iron	...	57	43	...	...	...	...
Hard solder for brass	...	50	50	...	...	...	...
Dipping brass	...	53	47	...	...	...	...
White brass	...	34	66	...	...	...	...
Lap alloy	...	12·5	87·5	...	...	...	...

SHEET BRASS AND WIRE BRASS

§ 28. For rolling into sheets, and drawing into wire and tubes, it is in the highest degree essential that the metals employed in alloying should be pure and consist only of copper and zinc. One of the most injurious substances to brass is antimony, which is occasionally found in common copper. Brass laminates well in the rolling mill in the cold, as long as it is kept sufficiently soft by occasional annealing, which, on account of the expansion of the mass by heat, releases the strain put upon its particles by the pressure of the rolls. The malleability and ductility of brass depend upon the composition; and for alloys of a full-yellow colour, the most suitable proportions are found between 66 to 73 per cent of copper and 34 to 27 per cent of zinc. The following table gives the composition of a few English and foreign varieties:—

Copper.	Zinc.	Tin.	Lead.
92·7	4·6	2·7	...
91·6	8·4	...	...
90	10	...	...
85·5	14·5	...	...
83	17	...	...
79·5	20	...	·5
76	24	...	...
75	25	...	...
73·5	26·2	·3	...
70	30	...	...
68	32	...	...
67	32	·5	·5
66	34	...	...
65	35	...	...

For hot-rolling, the alloys known as Muntz' metal, or more commonly yellow metal, are employed. They vary in composition from 56 to 63 per cent of copper and 42 to 37 per cent of zinc.[1] Mr. George Frederick Muntz of Birmingham took out his first patent for yellow metal as a sheathing for bottoms of ships and other vessels in 1832. The proportions specially recommended in the specification are 60 per cent of copper and 40 per cent of zinc; but these proportions may be varied from 56 up to 63 per cent of copper. Best selected copper and foreign zinc are directed to be used. The metal is cast into ingots, and rolled while hot into sheets, which, when finished, are pickled in dilute sulphuric acid to remove the adhering scale, and afterwards swilled in water. In the same year Mr. Muntz obtained a second patent for an improved manufacture of bolts, and other ship fastenings. Precisely the same proportions of copper and zinc are claimed as in the first patent. In 1846 a third patent was granted to Mr. Muntz for the use of an alloy consisting of 56 per cent of copper, 40¼ of zinc, and 3¾ of lead. In the specification it is directed that only the purest metals should be used, and that the alloy is to be cast into ingots, which are to be rolled at a red heat, and treated in other respects in the same manner as stated in the specification of the first patent. Dr. Percy states that he has succeeded in rolling brass well, which, on subsequent analysis, was found to contain not less than 8 per cent of lead.

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[1] Percy's *Metallurgy*, p. 619.

The theory assigned by Mr. Muntz for the application of his alloy is, that by exposure to sea-water the zinc is slowly and uniformly corroded over the entire surface, whereby the attachment of barnacles, etc., is prevented. Yellow metal sheathing has entirely superseded copper sheathing in the merchant service. Its special advantages are stated to be, that it keeps the bottoms of ships cleaner, and costs considerably less than copper sheathing. An experienced yellow metal manufacturer states that the proportion of zinc in the alloy should not exceed 38 per cent; and that if it exceeds this proportion, the sheathing is apt to become friable; and that if it is sensibly below this proportion, it wears away too rapidly. In 1874 an alloy composed of 62 parts copper, 37 parts zinc, and 1 part tin, was proposed by Mr. Farquharson for naval brass. To insure the best results he recommends that Australian or English B.S. copper be used. Unannealed, in rods or sheets of moderate thickness, the metal has a tensile strength of 67,000 to 72,000 lbs. per square inch, according to the amount of rolling it has received.

The composition of brass for ordinary wire drawing varies from 67 to 72 per cent copper, and 33 to 28 per cent of zinc. It has been stated that a little lead is sometimes added to brass intended for rolling, but this is not admissible in brass intended for wire drawing, as it diminishes the tenacity; and the ductility of a metal largely depends upon its tensile strength. Wire-drawers state that if brass wire is annealed immediately it has been taken off the drum, on which it has been wound during the process of wire drawing, it will fly to pieces. This effect is prevented by subjecting the coil of wire, after its removal from the drum, to strong concussion, by seizing one part of the coil with the hands, raising it, and heavily striking a bench with the other part, repeating the process several times.

Some kinds of brass wire undergo a molecular change in process of time, especially if subjected to vibration, and become extremely brittle. Brass chains, used to support objects, such as chandeliers, etc., have been known to lose their tenacity, become brittle, and break without any apparent cause. Ship bolts of Muntz' metal are sometimes found to undergo a singular kind of exfoliation, the metal on the exterior becoming separated, more or less completely, into concentric laminæ, from a solid cylindrical nucleus within.[1]

Cast-Brass

§ 29. The composition of brass used for castings varies considerably, and depends to a large extent upon the uses to which the cast articles are to be put, as also with the particular shade of colour it is desired to obtain. Thus various alloys for jewellery, having a reddish-yellow colour, are composed of from 82 to 90 per cent of copper, while those containing 60 to 70 per cent copper are of a full-yellow colour. The composition most generally used consists of 66·6 per cent copper and 33·4 per cent zinc, which is termed English standard brass. It works excellently under the rolls and hammer, and may be used also for wire drawing. Cast-brass generally contains more zinc than that which is to be worked into sheet or drawn into wire and tubing; it is therefore more fusible. Moreover, the materials are not selected with such care as is the case with those for rolling and wire drawing, so that cast-brass is often more impure than rolled brass, a large quantity of scrap being generally melted with new metal. The most common impurities are lead, tin, and iron. These metals are not always a disadvantage, for lead is generally added to the extent of from 1 to 2 per cent in brass required for turning and filing, as it gives sharpness to the metal and prevents fouling of the tools. The presence of a little tin is an advantage when hardness is requisite, as in the case of bushes, for example. A little iron hardens brass, and tends to increase its tenacity and elasticity. But it is not advisable to introduce metals other than copper and zinc, unless for specific purposes, as mentioned above. It should be borne in mind that however beneficial the addition of lead, tin, or iron may be in special cases, the simultaneous presence of two or all of these metals is generally injurious, whatever the action of one of them may be when present alone in the brass. In fact, it may be stated as a general rule, not without exceptions, that an alloy of two metals is more stable than that of three or more; and the greater the number of metals alloyed together, the greater will be the difficulty in obtaining uniform and sound castings. Lead especially has a tendency to separate out from the mixture in cooling, producing unsightly black spots, especially when present to the extent of 2 or more per cent.

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[1] Percy's *Metallurgy*, p. 621.

When the metal is cast in a large mass, or the castings are of considerable size, it is found that as the metal solidifies, a greater proportion of copper is found in the under portion than in the upper part of the casting, and the alloy is thus liable to be deeper in colour below than above. The constituents of an alloy of two or more metals tend to separate according to their respective densities, and the more numerous the constituents, and the greater the difference of their specific gravities, the more marked will this tendency be; but when the metals are in chemical combination with each other, no such separation will take place.

To test the difference in composition at top and bottom of cast-brass the two following experiments with the accompanying analyses were made by the author. Different varieties of brass were remelted together, so as to form two different qualities of brass, and cast into upright tapering iron moulds 4 inches high and about ¾ inch square.

	A		B	
	Top.	Bottom.	Top.	Bottom.
Copper . .	77·52	78·82	55·32	57·84
Zinc, by difference	22·15	20·74	44·26	41·58
Lead . .	·12	·22	·22	·27
Iron . .	·21	·22	·20	·31

TABLE OF DIFFERENT QUALITIES OF ORDINARY CAST-BRASS AS DETERMINED BY ANALYSIS OF COMMERCIAL SAMPLES

	Copper.	Zinc.	Tin.	Iron.	Lead.
French . .	71·9	25·1	1·0	...	2·0
,, . .	66·3	33·2	...	...	·5
French navy .	65·8	31·15	·25	...	2·8
English clock metal	67·0	27·27	1·0	·04	4·69
English brass .	67·0	32·0	...	...	1·0
,, .	64·6	33·7	·2	...	1·5
,, .	64·5	32·5	·3	·5	2·2
,, (very common)	61·6	34·8	·5	·6	2·5
,, ,,	60·2	38·04	·47	·61	1·68

Brass employed for the production of fine castings requires to possess other properties than those of being able to be filed and turned in the lathe. It must be thinly liquid when melted, and not in any degree pasty, so that it will readily flow into the minutest and most intricate crevices of the mould, and the texture must be fine-grained and uniform throughout. Moreover, as such castings specially require to be sound and free from pinholes, it must be capable of remaining thinly liquid until near the point at which it solidifies, so that the metal may be poured at the lowest possible temperature, thus enabling air and other gases, absorbed during the melting, to escape as much as possible before pouring. When the castings have to be subsequently gilded, it has been found that when the metal is similar in colour to gold, it requires less gold to produce the desired effect than when the brass is of a pale yellow colour. For this reason brass of reddish-yellow colour is preferred. The French have brought the casting of fine articles, as well as larger articles, to a high degree of perfection; clock-cases, statuettes, and other artistic ornamental work are manufactured by them on an extensive scale. The alloys used for these purposes are often called bronze, but they are generally brass, with the addition of a little lead and tin, which impart to the metal a bronze-like colour. The following are the proportions used for a few of the French mixtures:—

	I	II	III	IV
Copper . .	63·7	64·45	70·90	72·43
Zinc . .	33·55	32·44	24·05	22·75
Lead . .	2·5	·25	2·00	1·87
Tin . . .	0·25	2·86	3·05	2·95

The above alloys can be readily cast, worked with files and turning tools, and readily gilt.

Different Varieties of Brass

§ 30. **French Oreïde**—

Copper	90	85·5	82·75
Zinc	10	14·5	16·40
Tin	...	...	·55
Iron	...	...	·30

These alloys are distinguished by a beautiful gold colour which very closely resembles that of gold alloys. They are very ductile and tenacious, can readily be stamped and rolled, and admit of a fine polish. According to an old recipe oreïde is prepared in the following manner: "Melt 100 parts of copper and add, with constant stirring, 6 parts of magnesia, 3·6 parts of sal-ammoniac, 1·8 parts of lime, and 9 parts of crude tartar. Stir again thoroughly, and then add 17 parts of granulated zinc, and after mixing it with the copper by vigorous stirring, keep the alloy liquid for one hour. Then remove the cover of dross, and pour out the alloy."

§ 31. **Talmi or Talmi Gold.**—Also termed Abyssinian gold—

Copper	93·5	90	88	87	85	86·4
Zinc	6·5	9	11·5	13	15	12·2
Gold	...	1	·5	...	...	...
Tin	...	...	...	...	...	1·4

Talmi gold is the name given by the French, who use the foregoing alloys for cheap jewellery, which is distinguished by good workmanship, great durability, and a beautiful golden colour. The colour is retained for a considerable time, as it possesses a thin coating of gold, firmly welded to the alloy by rolling, and when the gold is of sufficient thickness the characteristic appearance may be retained for years without alteration. But many cheap imitations are manufactured and sold under this name which consist of common brass, gilded with a thin coating of gold.

§ 32. **Tournay's Alloy** is also used in the manufacture of cheap jewellery, as well as for buttons and so-called bronze ornaments. It is composed of 82·5 parts of copper and 17·5 parts of zinc.

§ 33. **Mannheim Gold, Similor, Prince's Metal.**—The composition of this alloy varies considerably, as will be seen from the following analyses of three samples :—

Copper	83·1	88·9	75
Zinc	10·0	10·3	25
Tin	6·9	·8	...

The first has a yellowish-red tint, and the second one a deeper red. Similor has been much used for buttons, and other stamped work requiring a reddish cast of colour.

§ 34. **Tombac.**—As stated on a previous page, tombac is a name applied to alloys which by some manufacturers are termed prince's metal, similor, and Mannheim gold. The name is used for alloys so widely different in composition and properties as to lose any significance it may have formerly possessed, and strikingly illustrates the great need of adopting Dr. Percy's proposition, that the different alloys of copper and zinc should be designated by their percentage composition. The following table will show the proportions of different mixtures :—

	Copper.	Zinc.	Lead.
Tombac for buttons .	99·15	·85	...
Red tombac of Vienna	97·8	2·2	...
,, ,, Paris .	92	8	...
Tombac (Bolley) .	91	9	...
Tombac of Oker. .	84·6	15·4	...
Tombac for buttons .	82·3	17·7	...
Tombac (Bolley) .	70·1	29·9	...
French tombac . .	80	17	3
,, ,, . .	82	17·5	0·5

§ 35. **Gilding Metal.**—Alloys of copper and zinc containing upwards of 80 per cent of copper have a reddish-yellow or red tint, and are used as a base for gilding. The more nearly the colour approaches to that of standard gold, the more highly is it appreciated for articles which are subsequently to be gilded. When such metal is required for rolling into sheet, it will be seen by reference to the table collated for the U.S. Board that the most malleable alloy is represented by the composition, 83 copper and 17 zinc. These alloys are also known by the name of red-brass, and as the reddish cast of colour is more agreeable to the eye than that of yellow-brass, they are frequently used for cast articles not requiring special hardness and strength. It has the reputation, however, of tarnishing quicker than ordinary brass. The properties of red-brass may be modified to suit special cases by the addition of tin, lead, and iron, the action of which has been already explained.

The following varieties of brass are distinguished from the preceding alloys by a characteristic yellow colour as contrasted with red brass.

§ 36. **Hamilton's Metal, Chrysorin, and Mosaic Gold.**

Copper . .	72	66·6	65·3	50
Zinc . .	28	33·4	34·7	50

Hamilton and Parker in 1826 claimed for the 50 per cent alloy that, after casting in the mould and cooling, it exhibits the colour of gold, and does not tarnish by exposure to air, even in the neighbourhood of the sea. They prepared it by fusing together equal parts of copper and zinc in a crucible at the lowest possible temperature, stirring constantly, and then adding a further quantity of zinc in small portions, till the right colour was obtained. This alloy is very flexible when strongly heated, but not adapted for cold rolling or wire drawing. It melts at a comparatively low temperature, and is used as a hard solder. The higher alloys given under the above names are malleable and ductile, and, as before mentioned, well adapted for cast ware.

The method of preparation described by Hamilton and Parker would be quite unsuitable for adoption on a working scale, for independently of the great waste of zinc, the composition of the alloy would be of an uncertain character. The usual plan is to melt the copper first and then add the zinc. The following plan has been recommended, but is open to serious objection for the same reasons as mentioned above. Bring into the crucible one-half of the zinc to be used; place upon this the copper, and fuse the mixture, under a cover of borax, at as low a temperature as possible. When the contents of the crucible are liquid, heat the other half of the zinc (cut into small pieces) until almost melted, and throw it into the crucible in portions; stir constantly to effect as intimate a mixture of the metals as possible.

§ 37. **Prince's Metal.**—A name given to various yellow alloys varying from 60 to 75 per cent of copper and 40 to 25 per cent zinc.

§ 38. **Bobierre's Metal.**—This is ordinary brass, consisting of 66 parts copper and 34 parts zinc. Bobierre introduced this alloy as especially suitable for ships' sheathing.

§ 39. **Macht's Yellow Metal** is composed of 57 parts copper and 43 parts zinc. It has a reddish-yellow colour, malleable when rolled hot, but not in the cold. It is said to be suitable for fine castings, as it possesses great strength.

BRASS CONTAINING IRON

§ 40. Many samples of brass and bronze made by the ancients have been found on analysis to contain iron, and probably they knew that the addition of iron to these alloys would increase their hardness and strength, and introduced it with that view. In more modern times the combination of iron with brass has engaged the attention of metallurgists, and several alloys, containing iron as an essential constituent, have been introduced from time to time. In 1779 James Keir proposed an alloy of 10 parts iron, with 100 parts copper and 75 parts zinc. Similar alloys to this, but containing less iron and different proportions of copper and zinc, were introduced under the names of "sterro-metal" or "Gedge's alloy," and "Aich's metal." Sir John Anderson, late superintendent of the royal gun factories, carried out a series of experiments with brass containing iron, and obtained some good results. The increased strength and hardness of such alloys were acquired at the expense of ductility and toughness. The great difficulty the above experimenter had to contend with was the uncertainty in the properties of the alloys containing iron.

§ 41. "**Sterro-metal**" consists of 60 parts copper, 38 to 38·5 zinc, and 2 to 1·5 iron. It was recommended as an alloy for sheathing for ships and other objects which are subjected to the continued action of sea-water. The presence of iron in this alloy imparts to it a strength equal to that of mild steel, and superior to that of wrought-iron. Brannt mentions a case in which a wrought-iron pipe broke with a pressure of 267 atmospheres, while a pipe of sterro-metal stood the enormous pressure of 763 atmospheres without cracking. This alloy also possesses great elasticity, and is therefore specially adapted for hydraulic cylinders. Such cylinders, when subjected to very high pressures, begin to sweat, the water from the inside permeating the pores of the metal. With sterro-metal the pressure can be raised considerably higher than with iron or steel, without moisture appearing on the outside of the cylinder.

Sterro-metal can be made very hard and dense by suitable mechanical treatment, which has as great an influence in modifying its properties as has the chemical composition. In rolling or hammering this alloy when hot, special care is requisite in regulating the temperature to which it is raised, as by too much heat it becomes brittle, and cracks under the hammer, or between the rolls. Baron Rosthorn tested a sterro-metal containing copper 55·04, zinc 42·36, tin 0·83, and iron 1·77 per cent, which gave the following results:—

Condition.	Tenacity in lbs. per square inch.
Cast	60,480
Forged	76,160
Cold drawn	85,120
Gun-metal Cast	40,320

The tenacity of ordinary gun-metal is given for comparison. The specific gravity of the alloy was from 8·37 to 8·40 when forged or drawn into wire. Another alloy from the same source contained copper 55, zinc 41·34, and iron 3·66 per cent.

§ 42. **Aich's Metal.**—This alloy is analogous to sterro-metal, and shows similar variations in composition from various analyses that have been made. Its chief properties are hardness and tenacity, the same remarks applying to this as to sterro-metal, with which it is practically identical. Alloys under this name contain from 0·4 to 3·0 per cent of iron. It has a golden-yellow colour, and is recommended for articles exposed to sea-water. The following analyses will give an idea of the composition:—

Copper	60·66	60	60·2	58·26
Zinc	36·58	38·2	38·2	41·00
Tin	1·02	...	...	...
Iron	1·74	1·8	1·6	0·74

§ 43. **Delta-metal.**—This alloy was brought out by Mr. Alexander Dick in 1883, and since that time has established a useful place for itself among modern brasses. The name "delta" was given to it by Mr. Dick, simply for the purpose of connecting it with his own name, delta being the Greek for the letter D, the initial of the inventor's surname.

As already mentioned, the great difficulty former experimentalists had to contend with, was the uncertainty in the properties of the alloys containing iron, and Mr. Dick set himself the task of ascertaining the cause of failure. He prepared various quantities of the alloy, apparently in exactly the same way, by dissolving wrought-iron in molten copper. The results showed many discrepancies, because the amount of iron dissolved in each sample was far from uniform. He then tried to find a method by which he might be enabled to introduce a known and definite quantity of iron, and succeeded by dissolving iron in molten zinc to saturation, and adding the same, with or without pure zinc, to the molten copper. But when the metals were remelted, oxidation took place, and the castings again varied in character, owing to the oxides thus formed dissolving in the alloy, and diminishing its strength and toughness. This second difficulty was overcome by adding a small percentage of phosphorus in combination with copper. In some cases Mr. Dick also introduces tin, manganese, or lead into the alloy, to impart special properties to it. The various alloys thus produced are now manufactured and sold under the name of "*delta*"-*metal.* The inventor claims that by his process the iron is chemically combined in the brass and bronze, as proved by the alloys not rusting when exposed to moist air, and by their indifference to the magnetic needle.

In a lecture by Mr. Macintyre before the Balloon Society on 15th November 1889, he states that "the properties which are combined in delta-metal—great strength and toughness, durability, resistance to corrosion, and a comparatively low price—render it of the greatest value for purposes of construction generally; and more especially for shipbuilding, marine engineering, and sanitary work. It can be equally well cast as forged, stamped and rolled hot, and drawn cold."

The power of delta-metal to resist corrosion by the acid liquors of mines has been proved by the Bonifacius Coal Mining Company of Westphalia. The Company made a series of experiments with a view to finding the relative corrosion of metals of suitable strength. Brass and gun-metal were not strong enough, and trials were made with steel, iron, and delta-metal. Rolled bars of each of these were immersed during a period of six and a half months in the water issuing from the pits at Kray, and then carefully re-weighed and photographed. The bars were 7½ inches long, and had a sectional area of ·62 square inches. The following were the weights of the three kinds of bars before and after the trial:—

	Wrought-iron.	Steel.	Delta-metal.
	lbs.	lbs.	lbs.
Weight of bars when put in	1·1805	1·2125	1·2787
,, ,, after 6 months	·6393	·6614	1·2633

In the *Schweizerisches Gewerbeblatt* of 8th June 1889 the following tests of delta-metal were recorded: "In the first locomotive engines of the Pilatus mountain railway, a material was required which could be cast, and possess at the same time great tensile strength and elasticity. Delta-metal was found to answer these requirements; the worm-wheels of the brake gear for the engines were of this material and worked very satisfactorily. The castings were tested by Professor Tetmayer of Zürich, the results showing a tensile strength of 21½ to 23½ tons per square inch, with an elongation of 30 to 40 per cent on a length of 7⅞ inches." Captain Locher also had the following tests made: One of the delta-metal pinions having been in use for a long time, the teeth had worn about $\frac{1}{32}$ of an inch, so that their thickness at the root was ⅝ inch, and at the top $\frac{7}{16}$ inch, by a breadth of 4⅞ inches. It was tested to show what power would be required to break such a tooth. The test, made by Professor Tetmayer, gave the following result:—

P .	5	9	10	12	14	15	16	17	18	19	20	21	21½
ΔL	0	0·015	0·019	0·059	0·098	0·133	0·169	0·208	0·244	0·295	0·354	0·472	broke.

P indicating the stress in tons, and ΔL the shortening in decimals of an inch of the distance L originally measuring 2¾ inch. Both as regards P and ΔL the results were unexpectedly favourable.

Samples of delta-metal tested at Lloyds gave the following results :—

Mark on test.	Description.	Size and specimen.	Original area.	Fractured area.	Permanent set in tons sq. in.	Maximum stress in tons sq. in.	Elongation in 8 inches. per cent.	Appearance of fracture.	Remarks.
No. 1	Square bar (annealed)	·5 dr. turned	·1963	·1288	Not taken	27·8	39	Silky & slightly laminated	...
No. 2	Flat plate (annealed)	1·44 dr. × ·128	·1843	·1102	12·1	30·0	36	Granular and silky	...
No. 3	Round bar	·495 dr. turned	·1924	·1352	23·4	32·1	23	,,	...
No. 4	Hexagonal bar	·49 dr. turned	·1885	·1256	25·0	31·3	11	,,	Broke in extension mark.
No. 5	Flat plate	1·44 dr. × ·128	·1843	·1620	13·7	35·4	14	Silky	...

The following test of delta-metal (forging) was made at Lloyds Proving House, Cardiff:—

The stalk of a valve spindle $\frac{9}{16}$-inch diameter at small end, drawn out of a 2-inch chill cast delta-metal billet, was cut from the forging, and tested with results as per copy below:—

(*The sample was reduced in centre for testing.*)

No. of sample.	Size.		Area.			Elongation in three inches.		Ultimate stress.		Remarks.
	Before testing.	After testing.	Before testing.	After testing.	Per cent of contraction.	Inches.	Per cent.	Actual tons.	Tons per square inch.	
1	·506	·412	·201	·133	34·32	·90	30·0	7·05	35·07	Broke in reduced part; good fractures.

WHITE BRASS

§ 44. Alloys of copper and zinc containing less than 45 per cent of copper cease to have a yellow colour. The alloys containing from 40 down to 30 per cent of copper are silver-white, and with less than 30 per cent of copper the colour passes from gray to bluish-gray, having a greater resemblance to metallic zinc as the proportion of that metal is increased. The silver-white alloys break with a conchoidal fracture, and the more zinciferous alloys with a fracture more or less crystalline. In consequence of the brittle nature of white alloys they cannot be used for rolling and wire drawing, but some of them are used for pressed work, when too strong a pressure is not required. Some of them are known by special names, thus :—

§ 45. **Birmingham Platinum** and **Platinum Lead** are used for certain castings, but the composition is variable, according to the taste of the manufacturer. The following will illustrate this point :—

Copper . . .	46·5	43	20
Zinc . . .	53·5	57	80

The above alloys are used for buttons by casting them in moulds giving sharp impressions, the letter or crest being subsequently brought out by careful pressing. Other alloys for buttons consist of—

Copper .	54	50	60	60	54½
Zinc . .	43	45	33½	30	45½
Tin . .	3	5	6½	10	...

§ 46. **Sorel's Alloys.**—These alloys are distinguished by great hardness and considerable tenacity. They cast well and can readily be detached from the mould. They are largely used for statuettes and other artistic work, which, after suitable bronzing, are brought into commerce as cast-bronze. The following mixtures are recommended :—

Copper	1	10
Zinc	98	80
Iron	1	10

Iron is used in the form of turnings, and melted with the copper and zinc under a layer of charcoal. But as zinc so readily volatilises it is advisable to employ zinc already containing iron, by which a more uniform alloy is obtained, with the minimum loss of zinc.

§ 47. **Fontainemoreau's Bronzes.**—These so-called bronzes are said to answer well for chill-casting, the metal being poured into iron moulds. By this means the alloys are rendered more homogeneous, because the rapid cooling prevents the separation of the constituents in accordance with their respective densities. The highly crystalline nature of the zinc is changed by the addition of copper, iron, or lead. The following are the proportions used:—

Zinc	90	91	92	92	97	97	99	99½
Copper	8	8	8	7	2½	3	1	...
Cast-iron	1	...	...	1	½	...	...	½
Lead	1	1	...	...	...	...	...	...

BRASS SOLDERS

§ 48. These are copper-zinc alloys employed for joining the various parts of articles together by fusion. The solder must, therefore, have a lower melting point than the body to be soldered, but the fusing point of the solder should approach, as nearly as it conveniently can, to that of the article, as a more perfect and more tenacious junction may thus be effected. Brass solder belongs to the class known as hard solders, or brazing solders. It may be stated as a general rule that the melting point of copper-zinc alloys is higher in proportion to the amount of copper present, and therefore any quality of brass may be made into a suitable solder by adding zinc or copper as the case may be. The alloy commonly used in soldering brass contains equal weights of copper and zinc. An easily fusible solder may be made with 34 copper and 66 zinc. In this case, however, it must be borne in mind that the joint would be much weaker than when the more difficultly fusible solder is employed, so that excess of zinc is to be avoided wherever possible. A readily fusible solder may be obtained by using 44 parts copper, 50 parts zinc, 4 parts tin, and 2 parts lead. Alloys containing lead are not to be recommended, since the lead tends to separate out and produce unsightly black spots, besides decreasing the strength of the joint. A good hard solder for the richer alloys of copper and zinc may be produced from 53 parts copper and 47 parts zinc. Brass solder is sometimes used for soldering iron and copper, and as these metals have a much higher melting point than brass, a much better quality of solder can be employed, and is indeed advisable in many cases, being much stronger. In these cases tin is often added as one of the ingredients, but it should be only sparingly used, as it increases the brittleness of the solder and thus becomes a source of weakness. The addition of tin to brass causes the yellow colour to pass into gray, or white, according to the content of tin employed, and mixtures may be obtained of a *yellow*, *yellowish-white*, and *grayish-white* colour. The following table indicates the different varieties :—

	Copper.	Zinc.	Tin.	Lead.	Colour.
Very strong	58	42	...	...	reddish yellow
Strong	53	47	...	...	,,
Medium	50	50	...	...	,,
,,	54½	43½	1½	½	,,
Easily fusible	34	66	...	...	white
,,	44	50	4	2	gray
White solder	57	28	15	...	white

In making solder it is very important that the constituent metals should be of good quality, as impurities seriously interfere with the colour, malleability, and strength of the solder; great care should also be taken to insure a thorough mixture, so that the alloys may be uniform in composition. Solder is often made by melting brass with the requisite addition of zinc, thereby insuring a more perfect union and less loss of zinc than is the case when zinc is added to molten copper. Solder is most commonly used in the granulated form, which is effected by pouring the molten alloy into water, or by pounding it in an iron mortar when strongly heated.

The most suitable mode of preparing brass solder is to melt the brass rapidly in a crucible, the metal being covered with a layer of the best powdered charcoal, and when thoroughly fused, to add the zinc, which has previously been heated to near its melting point. Stir vigorously for a few minutes to insure a thorough incorporation of the contents, skim the dross from the surface, and then pour, taking care that no dross or charcoal is carried over with the metal into the mould, or into the water, as the case may be.

One method of granulating is to take the ingot of metal from the mould immediately it has solidified and pound vigorously in a large iron mortar. Or to first raise the ingot of solder to the requisite temperature over a charcoal fire, and then crush to powder in an iron mortar.

Some manufacturers pour the molten metal into a ladle, and empty the contents of the latter from a considerable height into cold water, the metal in its descent passing through a wet broom, or similar contrivance, so as to divide it into fragments. The granulated metal is afterwards sifted through sieves of different sized meshes, so as to obtain the grains of uniform size.

Another plan is to pour the molten metal on to the surface of a large iron ball, placed in a shallow pan containing cold water, so that the top of the ball projects above the surface of the water. The metal is thus broken up into small fragments of fairly uniform size.

According to Krupp, the finest and most uniform product is obtained in the following manner:—

"At some distance above the surface of the water, serving for the collection of the grains, a horizontal pipe is arranged which is connected either with a powerful forcing pump or a water reservoir. Before pouring the metal the cock on the pipe is opened, so that the jet of water issuing from the pipe is thrown in a horizontal direction over the vessel containing the water. Upon this jet of water the molten metal is poured. The greater the force with which the water is forced from the pipe, the greater also the force with which the stream of melted metal is divided, and by this means it is possible, within certain limits, to obtain grains of a determined size." As will be seen from the above description, the scattering of the stream of molten metal is based on the same principle as that employed in diffusing fragrant liquids in the air.

When solder is granulated by pouring into water, it is necessary to remove the grains from the vessel as soon as the operation is completed, and dry them quickly, so as to avoid unnecessary oxidation.

MANUFACTURE OF BRASS

§ 49. Allusion has previously been made to the two distinct modes of making brass, known respectively as the *calamine* and *direct* methods; the former being almost exclusively used until within the last fifty or sixty years, but is now practically obsolete, at any rate in this country. In the ancient or calamine method, metallic copper is mixed with oxide of zinc and charcoal, and the mixture strongly heated for twelve hours or more, when the zinc, reduced by the carbon and carbonic oxide present, alloys with the copper forming brass. Such brass has been claimed to be of superior quality to that made by the direct process, but as great improvement has taken place in the qualities of brass of late years, it is very doubtful, if the manufacture of calamine brass were to be resumed, whether the value of the metal for most purposes would be superior to what the market can at present command. The reputed high quality of brass made by the old method could only be maintained by exercising great care in the quality of the ore and copper employed, and selecting ores of uniform composition to produce a product of uniform and determined properties. The cost of production of calamine brass is less than that of brass made by the direct process, but the former method is much more tedious and troublesome, requiring a much longer time than is consistent with modern requirements, and for small founders is quite unsuitable.

CALAMINE BRASS

§ 50. For calamine brass the ores were submitted to a preliminary treatment in order to remove as far as possible other compounds, such as those of lead, antimony, and arsenic, which would injure the quality of the brass. Native calamine was calcined to remove carbonic acid, sulphur, or other volatile matter, and form zinc oxide. The calcined ore was then ground in a mill, any galena removed

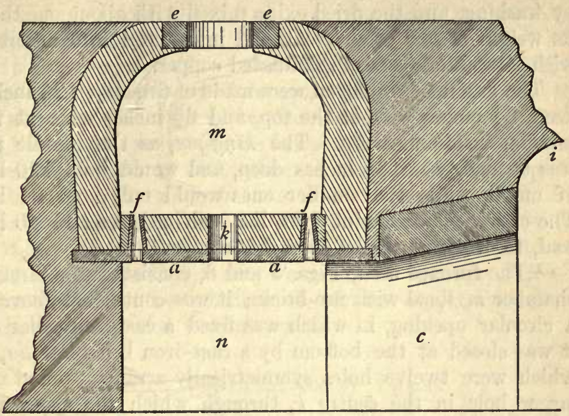
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Fig. 5.

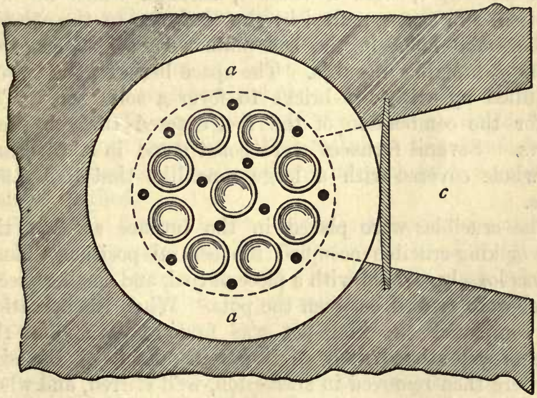
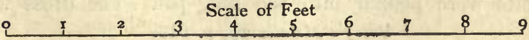


Fig. 6.

Scale of Feet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by washing, and the dried oxide mixed with about one-third its weight of coal or charcoal, and introduced into crucibles with alternate layers of granulated copper.

The crucibles employed were made of fire-clay, 12½ inches deep, 8¼ inches wide at the top, and 6¾ inches wide at the middle, inside measure. The *king-pot*, as the middle pot was termed, was 13½ inches deep, and would hold 120 lbs. of metal, while the smaller ones would only hold 84 lbs. The charge consisted of 100 lbs. calcined ore and 40 lbs. coal, to every 66 lbs. of *bean-shot* copper.

[1] The furnace used, Figs. 5 and 6, consisted of a circular chamber *m*, lined with fire-brick; it was contracted above to a circular opening, in which was fixed a cast-iron collar *ee*; it was closed at the bottom by a cast-iron bed-plate *aa*, in which were twelve holes symmetrically arranged round one larger hole in the centre *k*, through which the ashes and clinkers could be withdrawn from time to time. Below this plate was the ash-pit *n*, communicating in front by means of an air-way *c*, with a vault *i*, through which air was admitted, and access gained by the workmen to the ash-pit. In the small holes in the bed-plate were placed cast-iron twyers *ff*, tapering upwards. The space between the twyers was filled up with fire-bricks to form a solid bed. The air for the combustion of the fuel entered through these twyers. Several furnaces were constructed in a row, and the whole covered with a large cone like that of a glass-house.

The crucibles were placed in the furnace so that the large or king-crucible occupied the central position. Each pot was loosely covered with a piece of coal, and smaller pieces of fuel were packed between the pots. When the operation was completed the king-pot was first removed, and the contents well stirred with an iron rod. Each of the side pots were then removed in succession, well stirred, and when the brass in each case had subsided to the bottom the contents were poured into the king-pot. The dross was then skimmed from the surface, and the metal poured into suitable moulds.

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[1] Percy's *Metallurgy*, p. 613.

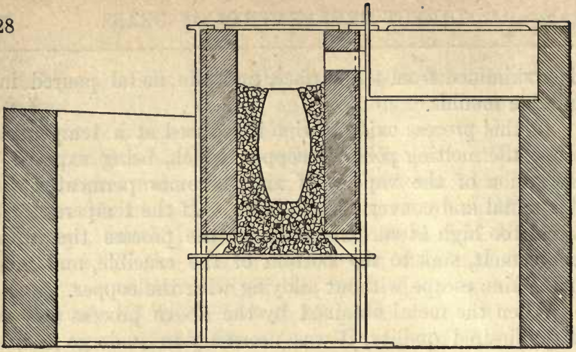
In this process oxide of zinc is reduced at a temperature below the melting point of copper, which, being exposed to the action of the vapour of zinc, becomes permeated with this metal and converted into brass. If the temperature be raised too high at an early stage of the process the copper would melt, sink to the bottom of the crucible, and much of the zinc escape without alloying with the copper.

When the metal obtained by the above process was not of the desired quality, it was necessary to undergo a fresh fusion with calamine and charcoal, or with copper, according as the copper or zinc was in excess.

DIRECT PREPARATION OF BRASS

§ 51. This method consists of melting copper and zinc together in the desired proportions, either in a crucible, or in a reverberatory furnace, the latter being used chiefly for Muntz's or yellow metal, where large ingots are required. Many attempts have been made to do away with crucibles for the manufacture of brass, and to substitute special furnaces of the reverberatory type; but the loss of zinc is so great, and the composition of the brass so liable to be uncertain, that even for yellow metal many manufacturers have discarded the reverberatory, and gone back to the old crucible method.

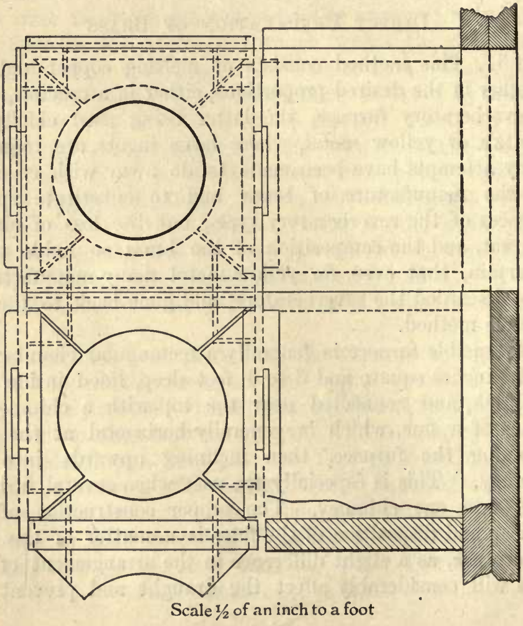
A crucible furnace is generally a rectangular chamber 12 to 16 inches square and 3 to 4 feet deep, lined inside with fire-brick, and connected near the top with a chimney by means of a flue, which is generally horizontal at the part adjoining the furnace, then inclining upwards into the chimney. This is especially the case when several furnaces open into one chimney. The proper construction of the furnace and disposition of the flues is a matter of the first importance, as a slight difference in the arrangement of the flues will considerably affect the draught and prevent the



Scale ⅜ of an inch to a foot

Vertical Section

FIG. 7.

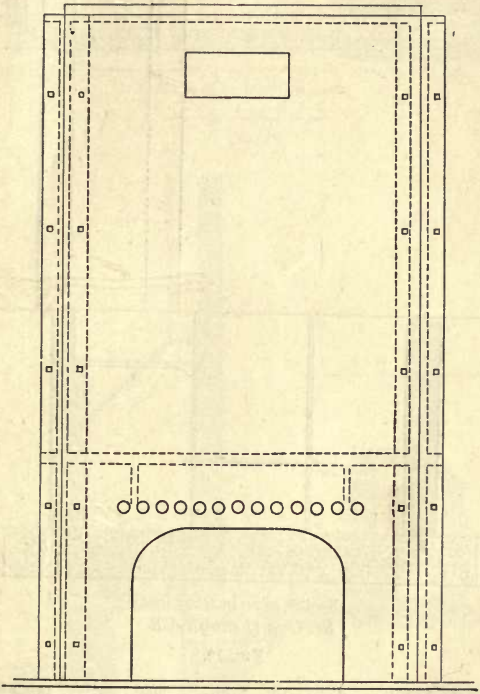


Scale ½ of an inch to a foot

Plan

FIG. 8.

attainment of that high temperature necessary in melting copper, brass, bronze, and similar metals. The section of the flue has a great influence on the working of a furnace,

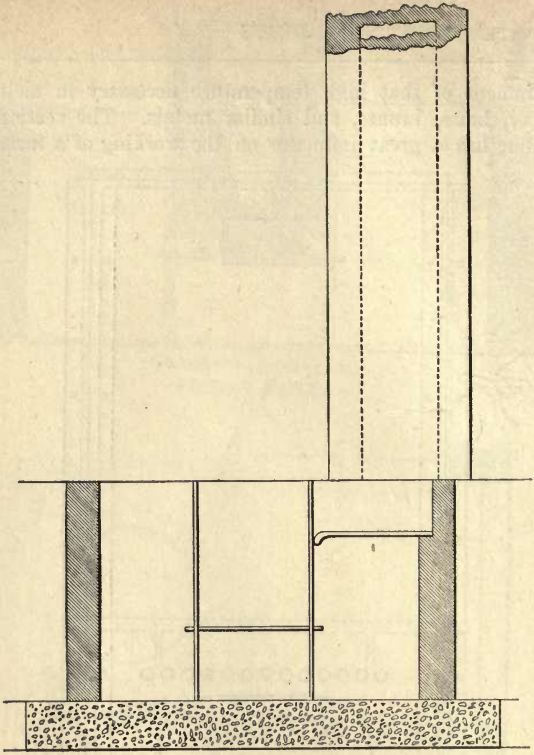


Scale ¾ of an inch to a foot

Front Elevation

FIG. 9.

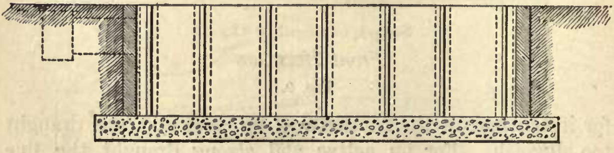
for if too narrow the friction will be great and the draught too sluggish. For an active and strong draught the flue must be wide and the chimney large and high. The section



Scale ¼ of an inch to a foot

Section through A.B

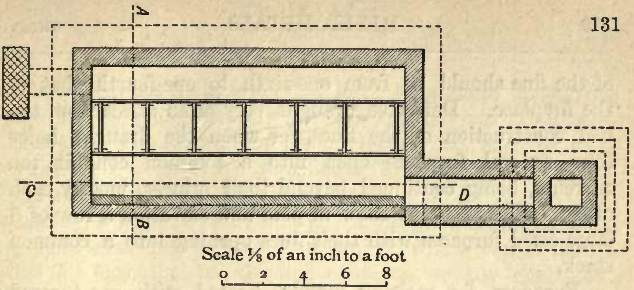
Fig. 10.



Scale ⅛ of an inch to a foot

Section through C.D

Fig. 11.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C
D
Scale ⅛ of an inch to a foot
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6
8

FIG. 12.

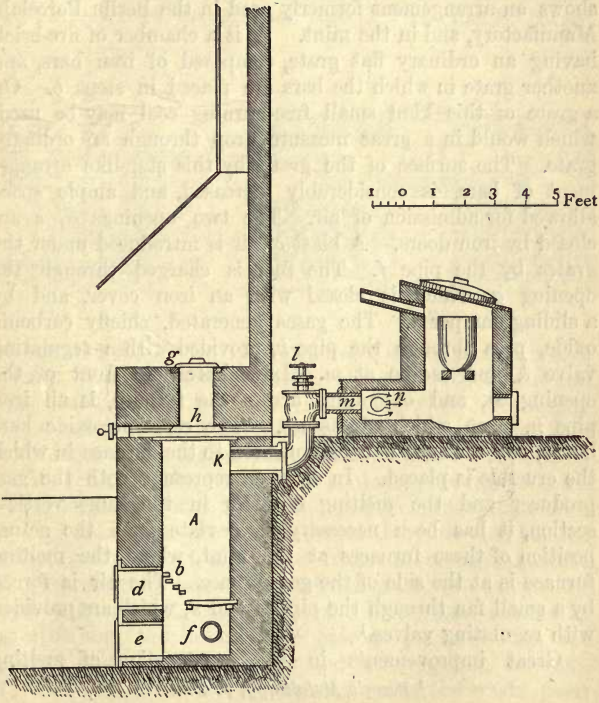
g
l
m
n
h
K
A
b
d
e
f
1 0 1 2 3 4 5 Feet

FIG. 13.

of the flue should be from one-sixth to one-fourth that of the fireplace. Defective draught very often arises from the bad construction of the flues, for when the draught holes from several furnaces open into a common conduit the currents, being continued beyond their orifices, modify each other. Figs. 7 to 12 show in plan and elevation a row of 6 large sized furnaces with their flues opening into a common stack.

Furnaces for melting metals, heated with gas instead of solid fuel, have been adopted in some works. Fig. 13 shows an arrangement formerly used in the Berlin Porcelain Manufactory, and in the mint. A is a chamber of fire-brick having an ordinary flat grate, composed of iron bars, and another grate in which the bars are placed in steps *b*. On a grate of this kind small free-burning coal may be used, which would in a great measure drop through an ordinary grate. The surface of the grate, by this step-like arrangement of bars, is considerably increased, and ample space allowed for admission of air. The two openings *d*, *e* are closed by iron doors. A blast of air is introduced under the grates by the pipe *f*. The fuel is charged through the opening *g*, which is closed with an iron cover, and by a sliding damper *h*. The gases generated, chiefly carbonic oxide, pass through the pipe *k*, provided with a regulating valve *l*, and escape at *m*. Immediately in front of the opening *m*, and extending across the furnace, is an iron pipe *n*, from which air issues. The carbonic oxide here burns, and the heat is communicated to the furnace in which the crucible is placed. In order to represent both the gas-producer and the melting furnaces in the same vertical section, it has been necessary to deviate from the actual position of these furnaces at the mint, where the melting furnace is at the side of the gas furnace. The air is forced by a small fan through the pipes *f* and *n*, which are provided with regulating valves.[1]

Great improvements in the construction of melting furnaces heated by gaseous fuel have been made during the last thirty years, notably through the labours of Messrs. Siemens. By the use of gas-producers fuel may be used which is too inferior for ordinary furnaces, and a higher temperature attained by the combustion of the gas formed, than by using solid fuel directly. A gas-producer is generally a somewhat rectangular chamber, in which fuel is burnt for the formation of carbonic oxide as already explained. Siemens's producer, Fig. 14, is lined with fire-brick; the side A is formed of iron plates lined with fire-bricks, and has a step-grate B, with wrought-iron bars C. The fuel is charged through the hopper D. The gas passes up the pipe E, which is cased with iron, and issues into a horizontal wrought-iron pipe, which conveys it to the regenerator, where it is highly heated before entering the furnace in which it is burnt, thus producing a much higher temperature. The waste heat of the furnace is not lost, but utilised in heating the regenerators. The arrangement of a Siemens's crucible furnace is shown in Fig. 15, where the pots are heated by the combustion of hot gas and hot air. The regenerators are chambers of open refractory brickwork, built in pairs, two pairs being required for each furnace; each pair being used alternately for absorbing the heat of the gaseous products from the furnace, and heating the gas and air required for combustion. By means of a reversing valve, the waste gases

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[1] Percy's *Metallurgy*, p. 201.

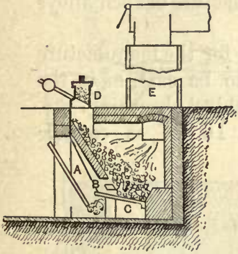

Fig. 14.

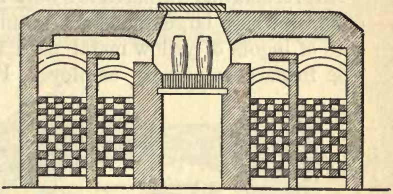

Fig. 15.

pass to the right or left pair at will. When the waste gases are passing down through the right pair, the cold air and producer gas are passing up through the left pair, the direction being reversed when sufficient heat has been absorbed. It will be observed that the combustible gas and air enter the furnace alternately at the right and left, according to which pair of regenerators is being used for heating them. By using gas for melting metals a neutral or non-oxidising flame can be obtained, which prevents loss of metal by oxidation, a manifest advantage in cases where it is necessary to preserve the composition of an alloy intact, and should be of great advantage in the manufacture of such alloys as brass.

Reverberatory furnaces are only used for the manufacture of brass where large quantities require to be cast, as in the case of ingots of yellow metal used for ships' sheathing, etc. The furnace commonly employed, Figs. 16, 17, is capable of holding about a ton of metal. It is somewhat rectangular in shape, with flat sloping bed, which inclines from the bridges and back towards the front, or working door. The bed is formed of fire-brick carefully set edgeways, or a well rammed sand bottom is used.

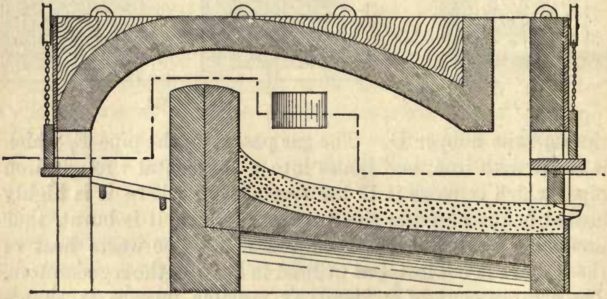
FIG. 16.

It is advisable that the copper should be melted first in an atmosphere of flame, so as to exclude the air as much as possible. Then the scrap and zinc, previously heated, are introduced, and the mixture thoroughly stirred as rapidly as possible, to prevent loss of zinc. Another plan, which finds favour with some manufacturers, is to melt the copper in the furnace, tap it into a large iron ladle, and add the heated scrap and zinc to the ladle, so that the metal may be poured into the moulds immediately after the necessary stirring required to mix the contents is effected.

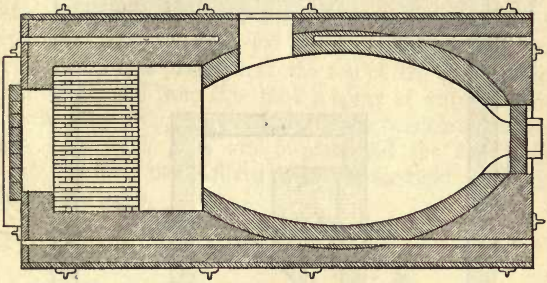

Fig. 17.

Scale of Feet

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11
12

The alloys of copper and zinc are easily formed, but when the zinc is added to the copper in the furnace the damper of the chimney should be nearly closed, and the fire should not be too brisk, since by having too high a temperature at this stage much zinc will be wasted. Moreover, when the metals are thoroughly mixed the surface should be covered with charcoal or sand, especially when it is necessary to raise the temperature before tapping. When the metal is ready for tapping the tap-hole is opened with an iron bar, and the metal run into a ladle. The surface of the metal is covered with charcoal, which keeps in the heat, and preserves the metal from oxidation by the air. The temperature of molten brass and bronze becomes rapidly lowered, and in order to produce sound castings, no time should be lost in pouring the metal into the moulds. All currents of air should be guarded against, and all openings tending to produce them should be closed during the time of casting.

§ 52. **Condensation of Zinc Fume.**—In the melting or manufacture of brass, the zinc, being of a volatile character, is to some extent volatilised, as before mentioned, especially when a reverberatory furnace is used, so that it becomes advisable to adopt some means for its recovery. The following plan is employed in some works. A syphon-

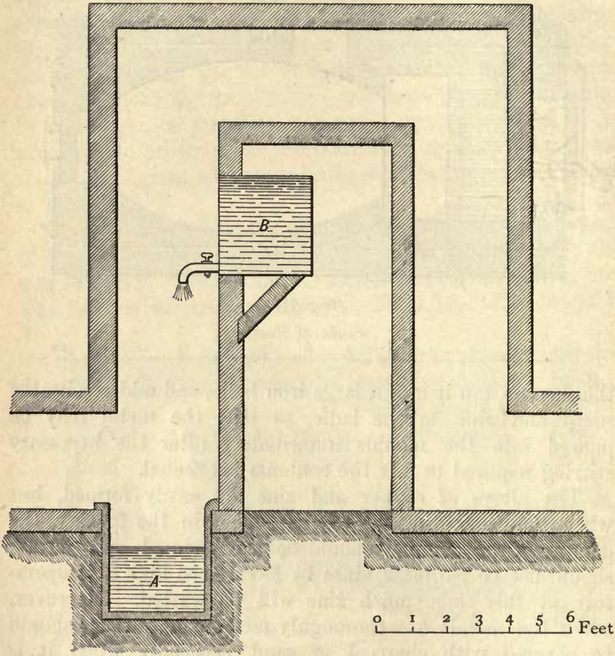


FIG. 18.

flue, Fig. 18, is placed between the furnaces and the chimney, and at the bottom of the flue is placed a tank about 3 feet wide by 4 feet long, as shown at A. This tank is filled with water, and when the heated gases from the furnaces pass over the water, a vapour arises, which causes the zinc fume to condense and settle down into the tank. Zinc fume consists largely of zinc oxide, which is periodically removed and sold to zinc smelters. A second tank is sometimes placed near the top of the syphon-flue, as shown at B, and from this tank a spray of water is allowed to continually drop, thus assisting in the condensation of zinc fume. The tank A is oval in plan, and the end projects outside the flue, and is fitted with an air-tight iron lid for cleaning purposes.

CASTING OF BRASS

§ 53. Great care and skill are required in casting brass after the alloying has taken place, as the success of the operation depends upon the discrimination displayed at this juncture. However perfectly the metal may be made in the furnace, the whole will be vitiated by an unsound or spilly casting, if the brass is required for sheet or wire. Two different modes of casting may be distinguished, viz. ingot casting, and plate or strip casting. In the former method the metal is poured into moulds producing brick-shaped ingots, which are to be remelted for ordinary castings or for further mixing. In the latter method the metal is poured into flat closed moulds, producing a strip or plate of metal to be rolled into sheets or otherwise.

§ 54. **Plate or Strip Casting.**—The moulds for strip casting are made of iron, and consist of two halves fastened together by a ring and wedge, so arranged as to be easily detachable from each other. The plan and section, Figs. 19, 20, will show the construction without further explanation.

The sizes of the mould vary considerably, depending upon the dimensions of the sheet or wire strip desired.

The following are the running sizes of the strips for sheet: $3\frac{1}{2}$, 4, $4\frac{1}{2}$, 5, 6, 7, 8, 9, 10, and 12 inches wide, 18 to 28 inches long, and $\frac{5}{8}$ to $\frac{7}{8}$ inches thick. The ordinary sizes of the strips for wire are $3\frac{1}{2}$ inches wide, $1\frac{1}{2}$ inches thick, and 7 feet to 7 feet 6 inches long.

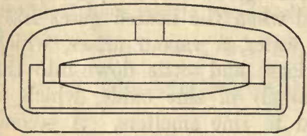


FIG. 19.

In order to obtain perfect castings the metal must be poured at the proper temperature; for if the metal is too hot a porous casting will result, and if too cold the mould will be imperfectly filled and the metal non-coherent in parts. Two grave defects are liable to occur in castings, arising from different causes, viz. *blowholes* and *spillyness.* When metals are melted in ordinary crucibles and furnaces a certain amount of air penetrates the metal, and certain gases, such as hydrogen and carbonic oxide, which are generated during the process. As the metal cools these gases are gradually liberated, and this evolution is greatly facilitated by mechanical agitation, which is usually effected by vigorously stirring with an iron rod. If the metal be poured at too high a temperature into a closed mould, some gases will be retained in the metal, forming cavities, and producing a honeycombed appearance, termed by the workmen "spuey metal." This is especially the case in a large mass, when the surface is rapidly solidified, while the interior remains in the molten state; the means of escape for gases from the interior being thus effectually cut off. For this reason it is a disadvantage to cool

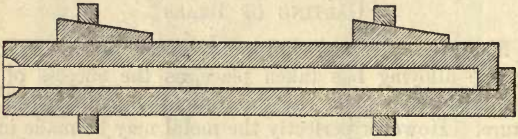


FIG. 20.

a casting too rapidly. The mould is therefore heated previous to running in the metal. The best plan of heating a mould is to have a plate of iron, which loosely fills the cavity of the mould, made redhot in a furnace, then placed inside the mould until the necessary temperature is attained. The iron plate is then withdrawn, the two halves of the mould detached, the interior surfaces oiled, and then powdered charcoal dusted on to prevent the metal sticking to the mould. Some coating material is absolutely necessary, but it is a frequent cause of defective casting, producing both unsoundness and spillyness. Now air is unavoidably carried unto the mould with the molten metal, and the oxygen unites with the carbon present to form the gas carbonic oxide; also hydrogen gas is generated by chemical change; if, therefore, such gases are not liberated before the metal solidifies, they will produce cavities in the metal. It is advisable then to use charcoal dust and oil very sparingly. The author is informed that a much better plan of blacking moulds is to use a mixture of resin and lard-oil. Three parts of resin are melted with one part of the best lard-oil, forming a viscous mass of about the consistence of treacle; this is applied to the surface of the hot mould by means of an ordinary paint brush. By the use of this composition much better and more uniformly sound castings are obtained.

A spilly casting is produced by the admixture of impurities in the metal, causing imperfect cohesion. This may be caused by loose particles of metal in the unalloyed state, but a more common cause is the presence of charcoal or dross, run into the mould along with the metal; or charcoal and dirt detached from the sides of the mould, when oil and charcoal are used as a preventative for sticking of the metal, as stated above. Great care should always be given to properly skimming the metal, and seeing that no dirt is carried into the mould. The metal should be poured in a clear and uninterrupted stream, otherwise serious flaws may occur, and the casting be rendered useless. It was formerly considered impossible to use iron moulds for plate-casting, as, through inexperience and ignorance of the conditions necessary for success, the castings very frequently turned out to be failures. Loam moulds were sometimes used, but, as they readily break, much trouble was experienced. For small work moulds of sand, thoroughly dried, were employed in some foundries; but sand is liable to crack and injure the plate of metal. For the most part granite moulds were used, and were considered to yield the best results. The preparation of granite moulds requires great care; it is requisite to line them with a thin coating of clay, which must be kept in such a condition as to insure the greatest uniformity of surface of the plates. The clay coating was covered with a thin layer of cow-dung to prevent it cracking. Brannt gives the following description of the method:—

"The prepared granite moulds are arranged in the following manner. The upper plate is suspended over the lower one, the space or mould between the two being limited by iron bars laid on the lower stone, which is a little longer than the upper one, and projects to the front, so as to form a lip or mouthpiece for receiving the metal. The plates are bound together with iron, and raised on one side so that they stand at an angle of 45° while the metal is run in. As soon as the casting is finished, and the metal is supposed to be solidified, the sheet of brass is carefully taken from the mould. With sufficient precautions such granite moulds can be used for a long time without the coating of clay being damaged, and the sheets turn out very uniform after the mould has once been heated by several castings. One and the same mould is frequently used continuously in order to keep it warm, and if it has to stand empty for some time, it is enveloped in a bad conductor, such as a coarse carpet, to prevent its cooling. If the mould is damaged it must be carefully mended, and the mended places sharply dried to prevent cracking."

Plate brass after casting is carefully inspected, and subjected to a mechanical cleansing previous to rolling.

During the rolling process the brass becomes hardened, and requires occasional annealing. As annealing blackens the metal, due to the formation of oxide, it is advisable to cleanse it in a bath of dilute sulphuric acid and scour with sand if necessary, and lastly to well swill in water. Sheet brass is annealed in a reverberatory furnace represented in section and plan, Figs. 21, 22. The furnace is so constructed as to prevent oxidation of the metal as much as possible. The fire-bridge *a* is high, and the charging door *b* is at the front. The waste gases and heat are drawn off by the flue *c*. To facilitate the introduction and withdrawal

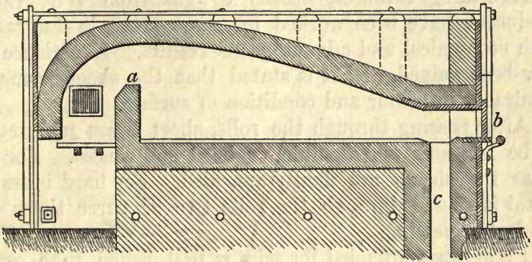


Fig. 21.

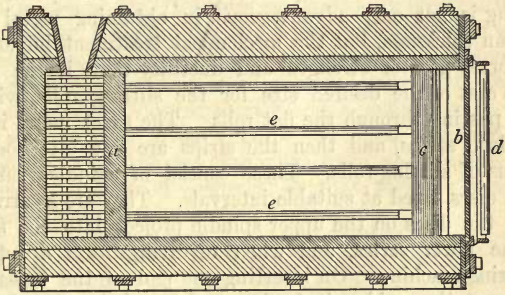


Fig. 22.

of the sheets a roller *d* is arranged at the front of the charging door, and on the bed itself are movable cast-iron bars *e e*, which favour the sliding in of the sheets. They also assist in the heating by isolating the sheets from the brickwork of the bed.

Annealing furnaces, heated by gas from Wilson's gas producers, have been worked for some years in Lancashire with economical and advantageous results. Experience has now been gained, and it is stated that the sheets come out admirably in colour and condition of surface.

After passing through the rolls, sheet brass may require to be left soft and flexible, or hard and elastic. For soft brass the sheets are finally annealed. For hard brass the metal is passed through the rolls two or three times after the last annealing.

Plate brass intended for wire is first rolled to a certain gauge to obtain the requisite thinness. This preliminary rolling is not only advantageous in obtaining metal of a certain thickness, but the mechanical treatment imparts to the brass greater strength and ductility than if the metal were cast of the desired size for the slitting rolls, without first passing through the flat rolls. The sheet metal is first cut into strips, and then the strips are cut into rods by means of slitting-rolls. These consist of spindles carrying steel discs, fixed at suitable intervals. They are so arranged that the discs on the upper spindle project into the spaces of the lower series, and when revolving form a rotatory shearing-machine. On inserting one end of the brass strip between the guides it is drawn forward by the shearing discs, and cut into rods, which, if necessary, are afterwards cut to length.

The exceedingly thin sheet-metal or leaf, known as Dutch metal, is not produced entirely by rolling, but by a combination of rolling and hammering. The metal is cast in thin plates and reduced to a certain thickness by rolling until a thin ribbon is obtained, frequent annealing being requisite. The ribbon is then cut into portions about one inch square, and a large number of these are piled on the top of each other, each piece being separated by a sheet of specially prepared tough paper, the whole forming a packet enclosed in parchment. The packet is then hammered on a block for some time with a heavy hammer, until each piece of metal is extended to sixteen times its former dimensions. These sheets are each cut into four, and the pieces so obtained made into a packet as before, except that a layer of gold-beaters' skin is placed between each sheet, and the beating repeated as before until the requisite degree of thinness is obtained. Careful annealing at certain stages of the process is requisite to prevent the sheets of metal cracking.

§ 55. **Ingot Casting.**—In casting ingots of brass, which have to be subsequently remelted, less care is required than with plate-casting, but when the metal is employed for casting various articles in sand moulds, equal care is absolutely necessary. Crucibles are invariably used for mixing and melting brass for the above uses, and the metal poured directly from the crucibles into the moulds. Brassfounders' melting-pots are made of plumbago mixed with fire-clay and coke-dust in varying proportions, a description of which has already been given. These crucibles, although more expensive than clay ones, are much more durable and stand a greater number of meltings, so that they are now most generally used.

§ 56. **Air-drying Stove.**—The flue from the casting furnaces is generally used for heating the stove, and so constructed as to pass underneath the drying stove, Fig. 23. Where such an arrangement is not convenient an ordinary fire-grate is employed. The flue in both instances passes under the stove, and the arch is constructed of specially shaped fire-bricks, as shown in Fig. 24. The size of drying stoves varies according to the requirements. Those used for drying cores for tube-casting are generally 6 feet long, 4 to 5 feet wide, and not less than 6 feet high. The bottoms are made of cast-iron plates, 1 inch thick, and perforated with $\frac{1}{4}$ inch holes to allow the heat to pass upwards from the flue.

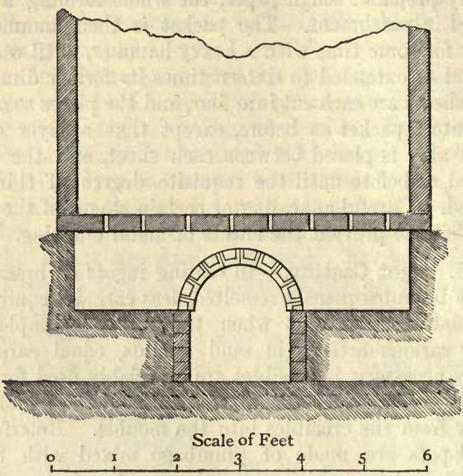


FIG. 23.

The stoves for drying ordinary brassfounders' cores are similar in construction, with this difference, that shelves are

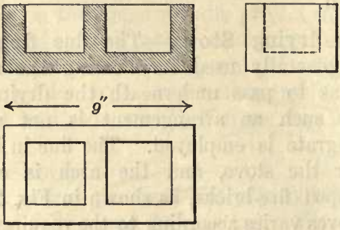


FIG. 24.

also arranged in them, upon which the cores to be dried are placed.

MOULDING AND CASTING

§ 57. The valuable property of moderate fusibility, which many metals possess, enables articles of various kinds to be produced from a pattern, by impressing upon sand or other mobile material a copy of the pattern, and subsequently pouring molten metal into the cavity thus obtained. The solidified metal will be an exact counterpart of the impression in the sand.

The term "moulding" is used to signify the various operations concerned in preparing the impression to receive the metal, and the term "casting" is applied to the whole operation of producing the object, and includes both the moulding and running in the metal. The principal materials used in moulding are:—sand of various kinds, loam, plaster of Paris, blackening, pea-flour, etc.

Sand is by far the most common, and certainly the most perfect and convenient moulding material. The properties which make it so valuable are its porosity, adhesiveness, mobility, practical infusibility, and unalterability. By means of its porous nature the gases generated during pouring of the metal can freely escape; by its adhesive property a perfect impression is produced from any given pattern; the metal is firmly retained when run into the mould; by its mobility it gives way sufficiently, and flows into the finest markings of the pattern when pressure is applied; and in virtue of its non-fusibility and chemical unalterability, the heat of the molten metal does not fuse it, or change its chemical composition. The best kinds of moulding sand employed for casting brass have been found to have an almost uniform chemical composition, varying only in size of grain or aggregate form. It contains—

Silica . . .	93 to 95 parts
Clay	6 to 3 ,,
Iron oxide . . .	1 to 2 ,,

Sand containing other metallic oxides, such as lime and magnesia, is too weak or too close—that is to say, it will not retain its form, or it will cause the metal to boil by its closeness, the gases not having a free means of escape. When the oxide of iron is greater than the above proportions the sand is liable to fuse, and unite with and blister the surface of the casting, generate gases, and cause blowholes in the metal. Different kinds of castings require different kinds of sand. One class necessitates the use of a porous and yet adhesive sand; in another the sand must be very fine, free from grit, and very adhesive, so as to conform to the finest parts of the pattern.

The best moulding sand is often found along the banks of large rivers, in the vicinity of granite or slate mountains; or in coal districts, where the river flats are largely composed of sand. In such localities it sometimes contains too much oxide of iron, and is liable to melt; but this may be modified by mixing it with coke-dust. Kampmann states that a good sand for moulds may be artificially made from the following mixture:—

Fine quartzose sand	93
Red English ochre	2
Aluminous earth, the least possible calcareous	5

A valuable casting sand is obtained from the new red sandstone at Birmingham. The value of the quarry of this sand at the Old Cemetery was estimated at £20,000 sterling.

Core-sand.—This sand should be coarse, porous, and very adhesive, such as rock-sand, the fine material from abraded rocks; free-sand from river-banks, or from the sea-shore, and pounded blast-furnace cinder, etc., are often mixed with fine, strong sand, and a little clay to make it adhesive. In each case fresh sand must be used for a core, as old sand, burnt sand, or sand mixed with coal is not advisable. One part of clay mixed with nine parts of free-sand is sufficiently strong for small and simple cores, but for large and complicated ones a stronger sand is required.

Parting-sand.—A substance which does not retain moisture is required for this purpose. Red brick-dust is preferred, but free-sand, sea and river sand, and blast-furnace cinder are also used.

Facing-sand.—If molten metal is allowed to come in immediate contact with some kinds of fresh sand, a surface fusion of the sand takes place, with consequent roughness of the casting. If the raw sand is too coarse the metal will penetrate the sand to some extent, and also produce a rough casting. To avoid this defect the sand is coated with carbon or carbonaceous matter in the form of fine dust. Carbon and coal dust do not adhere well to old sand, so that in such a case the mould is first dusted with pea-flour and then with charcoal. Charcoal powder is also mixed with one-tenth of its volume of fine sand, and used as a facing for small castings.

The success in casting is not only dependent on the manipulative skill of the founder, but also on that of the pattern-maker. If a wood-pattern is required, pine, mahogany, oak, and other kinds of wood are sometimes used. In the brass trade boxwood is most commonly employed. The pattern is made larger than the size of the required casting, about ¼ inch per foot being allowed for shrinkage and finishing. Patterns with their edges at right angles do not leave the sand without disturbing the impression, so that they are made to taper in the parts which enter the sand. Sharp angles in a pattern should be avoided as much as possible, as they leave an edge of sand which is liable to break off on removing the pattern, and produce a defect in the casting. Such a defect in the mould is remedied by mending the broken places with sand before pouring. Wood patterns should either be varnished or brushed with black-lead to prevent absorption of moisture, and enable them to part from the sand more freely. Bees-wax or plaster of Paris is used for stopping up holes and cracks in the wood. It often happens, when a permanent pattern is required, that a metal pattern is cast from a wooden one, and the former then used as a pattern from which castings are obtained. In such a case the wood pattern should be made much larger than the finished articles, to be subsequently produced, are required. This is to allow for the double shrinkage, and for the dressing of the cast work. Sometimes patterns must have pegs of wire attached to enable the caster to lift them easily out of the sand. Besides wood and metal, casting patterns are often made of clay, plaster of Paris, or wax.

Moulding-sand is kept in position by means of shallow iron frames, open at top and bottom, and called flasks. These are of various sizes, each side of a frame having a depth of about 3 inches. A flask consists of two parts, as represented in Fig. 25, where A is the upper and B the lower frame; or they may be termed the peg-side and the eye-side respectively. In addition to the two parts shown in the figure, a third frame is often used, termed the *odd-side*, which is subsequently described.

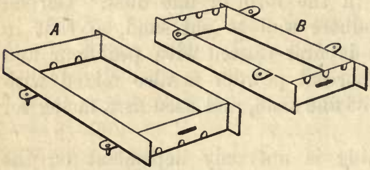


FIG. 25.

§ 58. *To make the odd-side.*—The sand is first tempered with water, and passed through a rough sieve with about five meshes to the linear inch. It should be noted here that black or old sand does not hold together so well as raw sand, the black sand containing burnt flour, charcoal, and brick-dust; and probably the sharp edges of the particles of sand are partly worn off by frequent use, and cannot be wedged so firmly together. If black sand only be used the castings are liable to be *blown*, the material not being sufficiently porous to allow the air and other gases to escape.

The moulding is commenced by placing one of the frames, often termed the *she-side*, on the top of a flat board, then dusting the inside with parting sand, then adding some raw sand, and filling up with black sand. The sand is rammed down tightly with the palms of the hands, then with the knuckles, and finished with a mallet. The surface is next scraped level with a straight-edged piece of wood, a board placed on the top, and the whole frame with its contents inverted.

The patterns are now carefully laid on the mould and the dust bag shook over them; this will leave a clear outline of the patterns upon the sand, which is then cut away in order to let them in half-way. The "odd-side," which is always the "peg-side," is now fixed to the lower frame, parting sand added, and then a mixture of raw sand and black sand, and finally black sand to complete the mould as before. The facing-sand, which is sometimes mixed with black sand, half and half, must be pounded in a mortar and passed through the meshes of a fine sieve. The odd-side must be rammed down as tightly as possible, as upon the compactness of the sand the future success of the operations depends. A board is then placed on the top and the "flask" turned over. The board which now forms the top is hammered to loosen the patterns, and the "she-side" taken off and broken up.

The "odd-side" contains the patterns, and is now ready to mould from. A frame is fixed to the "odd-side," sand pressed in as before, then covered with a board, and the whole inverted. The patterns are then loosened by hammering the top board, and the odd-side, which now contains perfect impressions of half of each of the patterns, is removed, leaving the patterns in the she-side. A frame containing pegs is now fixed to the she-side, sand added and pressed as before. This peg-side is then removed and placed aside, leaving the patterns in the "she-side." The "odd-side" is then placed on the "she-side," the flask again inverted, the patterns loosened with the hammer, and the she-side removed, leaving the patterns in the "odd-side" ready to start again. It will thus be seen that the "odd-side" is used over and over again to make other moulds from, a group of five to six moulds constituting a *heat*. About six heats of common brass work would be considered a fair day's work. The number of moulds constituting a heat is regulated, however, by the size of the crucibles and weight of the castings.

Before the molten metal is poured in, the impressions from the patterns in the sand must be connected by the principal *ingates* or channels by which the metal is run into the mould, the sand being scooped out by a special tool, termed a "drawer." This operation, although apparently simple, really requires much judgment and experience, especially in large work, in order to obtain the requisite amount of metal to feed the impressions. The runners are generally made on the "she-side," but sometimes they are employed on both the "she-side" and "peg-side." The "cores" are generally laid in the peg-side. For common work the metal is poured into the moulds while in the damp state, the impressions having been previously dusted with flour or charcoal.

§ 59. **Fine Work.**—For fine castings the moulds, after being made, are dried before a fire, previous to dusting, and then dusted with powdered charcoal. For *single-face* only one side of the mould is dried. For very delicate work the face of the mould is smoked with a torch composed of pitch. In this case, after drying and torching, the moulds must be again brought in contact with the patterns before being screwed up, and the soot being in a very finely-divided state, the impression is brought out clear and sharp. The caster uses a clayey sand, termed "loam," to mix with his ordinary sand for fine work, and for that reason the moulds must be well dried. By the use of loam the chased and sharp corners of the impressions hold together better. When loam is used facing sand is necessary, and this being of a more porous nature than loam sand, permits the gases more freely to escape when pouring, and thus prevents blowholes in the work.

When moulding thin scrolls, or when the pattern has a thin part, the moulds must not be rammed too hard, for, as the metal contracts on cooling, if the sand does not give way the metal will crack and the castings become what is termed *seared.* The caster overcomes this difficulty by damping the thin part of the impression with charcoal and water, which renders that part of the mould soft and yielding when the metal cools.

§ 60. **Cores.**—When the objects to be cast are required to be hollow, they are then "cored," as it is termed. It is advisable in all cases, wherever possible, to allow the pattern to deliver its own core. This can be done by making the pattern to "leave" half-way, or by turning it taper all through. For example, in Fig. 26 *a* to *c*, the light shaded portion marked *d* represents the core. In many cases this method cannot be adopted. Sometimes the pattern is moulded as though for a solid casting, and the sand core pushed out of the pattern, and fixed on the face of the mould with a splint of wood or a nail, before pouring in the metal. For many articles core-prints have to be made on the pattern, and these imprint in the mould the places where the ends of the core will subsequently be supported. The core bearing must always be of the same diameter as the prints in the pattern.

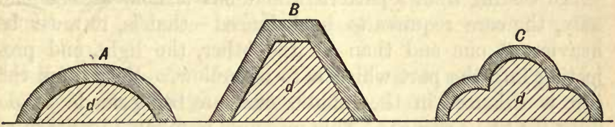


FIG. 26.

Core-stocks.—These are core-boxes, generally made of plaster of Paris or wood, the interior of which contains a cavity, of the desired shape of the interior of the object to be cast. Core-stocks are made as follows: The core-bearing is placed half-way in the sand, and pieces of metal or wood placed round to form an enclosure. Plaster of Paris is then poured over the bearing in this enclosure, and left until it has completely set. The plaster cast along with the bearing is then removed from the sand, trimmed up, and hollows cut out of the sides, and left to dry, when the bearing becomes loose. This forms one-half of the core-box. The plaster cast is then well oiled, placed in sand, an enclosure made as before, and plaster of Paris poured in. When the whole is set and dry the two parts are separated, and the bearing removed. The core-stocks are then ready for use. Should any difficulty be experienced in getting the parts asunder, the stocks are placed in an oven and heated, when the parts are readily separated. These stocks are then generally used to cast from in brass or iron, so as to form permanent core-boxes.

In casting from a pattern which has a hole at one end only, the core requires to be balanced—that is, it must be heavier at one end than at the other, the light end projecting into the part which is to be hollow. Very often the core is balanced in the middle, one core being made to do duty for two castings. This principle is taken advantage of in patterns which are undercut, as in the flange of a pulley. This process is called false coring.

§ 61. **Figure Casting, etc.**—This most complex part of the founders' art is done by the false-coring process, the patterns being generally solid. The figure to be cast is laid as far into the sand as will enable it to leave properly, and when the caster comes to an undercut part, he dusts it with parting sand, and fits in a piece of sand. When he comes to another undercut part he uses more parting sand, and rams more sand in as before. In this way piece after piece is successively laid on the pattern, until he comes to a part which will leave the sand without breaking any portion of it. This part is then moulded, removed, and each separate piece of core taken out with two needles, in order to remove the pattern. The moulds and pieces of core have to be dried and carefully replaced, and mended if required. The impression after dusting, etc., is then ready to receive the metal. The pieces of sand are removed with two needles stuck in a piece of wood. The relative position of the cores are readily recognised by their irregular forms.

Birds, insects, and parts of plants may be cast by fixing the object to be cast in the centre of a box by means of pieces of cotton. China clay mud, plaster of Paris, or any substance which is not combustible is thrown into the box, and the object covered. Plaster of Paris crumbles to powder when heated, but if it be mixed with a little potassium sulphate, alum, or borax, the plaster can be heated to redness without crumbling. When the object is covered with the non-combustible matter, sand is added until the box is full. It is then dried, and the box and its contents heated sufficiently to burn the object to ashes, which are carefully blown out. A place is left as usual for the metal to be poured in.

Dr. Branson's Method.—This method was devised for taking copies of ferns, seaweed, etc. A sheet of gutta-percha is softened in boiling water, put upon a warm metal plate, and dusted over with bronze powder; this dries the surface, makes it smoother, and prevents the specimens sticking to the plaster. A fern is then laid on the top of the gutta-percha, then a smooth plate, and pressure applied. The plate is removed when cold, and from the beautiful impression thus prepared a cast is taken in plaster of Paris, and a casting may be obtained in type-metal, brass, etc.

Some articles, such as a pattern for a paraffin lamp-stand, are moulded as follows: The pattern is moulded in wax or plaster, laid upon a board, and an impression of the outside taken. The mould is then inverted and the pattern removed. Parting sand is dusted in, a frame fixed on the top, and an impression taken of the sunken sand-mould. The thickness of the casting is then determined by placing a layer of clay between the two moulds. Each part of the casting is, in this case, of the same thickness throughout.

DIPPING AND PICKLING BRASS

§ 62. The layer of oxide on the surface of brass, which has been heated in contact with air, is removed by dipping in acid liquids and finally swilling in water. The corrosion may be also due to sulphur and other bodies derived from the fuel, and with soldered articles from the fluxes used. It often happens that the incrustation is very persistent, and if it is attempted to remove it rapidly by using strong and hot aqua-fortis, much of the brass is also dissolved producing a very rough surface. For this reason it is preferable to employ at first a weak liquid containing salts of copper and zinc from previous operations, and termed pickle, which slowly removes the surface coating and leaves the metal smooth. Dilute sulphuric acid is also used as a pickle for sheet copper, being slower and more uniform in its action in proportion to the degree of dilution. Nitric acid, which is the chief constituent of aqua-fortis, exerts a more powerfully solvent action on zinc than on copper, so that the surface of dipped brass assumes a warmer tone, shading more or less into a reddish-yellow. To some extent the colour may be varied by using aqua-fortis of different strengths, probably depending on the component metals being dissolved in different ratios by acids of varying densities.

Nitric acid, containing a certain quantity of nitrous acid, is capable of producing different shades of colour. To obtain such a mixture small quantities of organic substances are used for the purpose of generating nitrous fumes, by the action of concentrated nitric acid upon them. Thus saw-dust added to strong nitric acid imparts an orange-yellow colour, due to the partial decomposition of the acid and the formation of nitrous acid.

Dead dipping is the name applied to the process of producing a dead yellow surface on brass-work by dipping in suitable liquids. The work is first pickled in dilute or spent acid until the scale can be removed by rubbing. It is then well swilled and placed in stronger acid, which acts much more promptly, giving rise to a frothy appearance, this is removed by rinsing the work in water, after which it is dipped in strong nitric acid for a few seconds, washed in water, and then washed in water containing dissolved *argol*, finally being dried in hot saw-dust. The argol solution is said to prevent a brownish discoloration, or mottling of the surface, which would otherwise occur. In this last dipping it is important that each article should be dipped separately, and not a number strung together on wire, as is often the case in the former dippings.

CHAPTER III

BRONZE

§ 63. The term "bronze" will be applied in this work to all alloys consisting chiefly of copper and tin. These metals have been known from very remote times, and the importance of the mixture of copper and tin appears to have been among the first discoveries of the metallurgist. Instruments of various kinds were fabricated from these alloys, and weapons were made with a keen cutting edge, harder than iron, and almost rivalling that of steel. The bronzes of the ancients varied considerably in the proportions of the ingredients, for in the main copper and tin only were used, according to the purposes for which they were intended. Sometimes other ingredients were added, either purposely to produce a given effect, or it may be, in some cases, that bodies other than copper and tin were present as accidental impurities. This would arise from the use of impure metals, derived largely from ores of copper or tin associated with other ores, which is often the case.

Of late years very great attention has been devoted to the study of copper-tin alloys, and those proportions of the constituents which have been found by experience to give the greatest strength and the keenest cutting edge are the same as those used by the Greeks and Romans for their weapons of war and of the chase. The effect was produced by causing the bronze to undergo a process of hammering, as well as a method of hardening, by heating and slow cooling.

Many ancient coins were made of bronze, containing in some cases lead, zinc, or iron. The following table will show the composition of some ancient bronzes :—

COMPOSITION OF ANCIENT BRONZES

	Authority.	Specific gravity.	Copper.	Tin.	Zinc.	Lead.	Iron.	Remarks.
Old Attic coin . .	Mitscherlich	..	88·46	10·04	..	1·05	..	..
Athenian ,, . .	,,	..	76·41	7·05	..	16·54	..	..
,, ,, . .	R. Wagener,	..	83·62	10·85	..	5·53	..	..
Macedonian ,, . .	O. Monse	..	87·95	11·44	..	..	..	..
Coin of Alex. the Great	E. Schmid	..	95·96	3·28	..	0·76	..	..
,, ,, ,,	..	..	86·72	13·14	..	..	..	335 B.C.
,, Philippus V. .	..	..	85·15	11·10	..	..	..	200 ,,
,, Athens . .	..	..	88·41	9·95	..	..	..	..
,, Ptolemy IX. .	..	..	84·21	15·59	..	..	..	70 B.C.
,, Pompey . .	..	..	74·11	8·56	..	16·15	0·28	53 ,,
,, The Atilia Family	..	..	68·72	4·77	..	25·43	..	45 ,,
,, Augustus & Agrippa	..	..	78·58	12·91	..	7·66	..	30 ,,
Roman sword blade .	..	..	91·39	8·38	..	..	..	..
,, ,, ,, .	..	..	89·3	10·7	..	..	..	..
Ancient bronze nails .	..	..	95·1	4·9	..	..	..	..
,, soft bronze .	..	..	90	10	..	..	..	..
,, medium bronze	..	..	88·9	11·1	..	..	..	..
,, hard bronze .	..	..	87·5	12·5	..	..	..	..
Roman As . . .	Phillips	8·59	69·69	7·16	..	21·82	0·47	500 B.C.
Coin of Julius & Augustus	,,	8·64	79·13	8·0	..	12·80	..	42 ,,
Broken sword blade .	,,	..	85·62	10·02	..	..	0·44	..
,, spear head .	,,	..	99·71	..	..	..	..	Sulphur. 0·28
Celt (Ireland) . .	,,	..	90·68	7·43	..	1·28	..	..
,, ,, . .	,,	..	89·33	9·19	..	..	0·33	Sulphur. 0·24
Celtic weapon . .	Fresenius	..	92	6·7	..	0·69	0·29	Nickel. 0·31
Coin of Claudius Gothinus	..	8·81	81·6	7·41	..	8·11	..	Silver. 1·86
Celtic vessels . .	..	..	88	12	..	..	..	..
Gallic bell . . .	Girardin	..	85·9	14·1	..	..	..	..
Bells of twelfth century	,,	..	76·1	20·7	1·6	..	1·6	..
Drinking horn . .	Donovan	..	79·34	10·87	..	9·11	..	..
Bronze ring . . .	Salvetat	..	75·55	23·52	..	·47	..	..

It will be observed from an examination of the foregoing table that the principal constituent of bronze is, in all cases, copper, the other components being added to harden or otherwise modify its properties, according to the purpose for which the alloy is intended. Tin has the property of hardening copper, as already stated; the alloys are capable of taking a high polish; they present a beautiful metallic lustre, and with their moderate melting points, and fluidity when melted, form excellent alloys for casting. In certain proportions copper-tin alloys emit a beautifully clear sound when struck, the quality of which may be modified by slightly altering the composition of the mixture. Certain varieties of bronze containing, in addition to copper and tin, zinc, lead, manganese, iron, silicon, or phosphorus, are now largely manufactured for machine and engineering purposes.

The great feature of modern bronzes is the substitution of triple and quadruple alloys for the old dual alloys. French bronzes nearly always contain the four metals, copper, tin, lead, and zinc, and in some cases small quantities of nickel, arsenic, antimony, and sulphur. Each of these elements exerts an influence on bronze in proportion to the amount present, and if such influence is prejudicial for certain uses, care must be taken in the selection of the metals employed for admixture. Impure copper is by no means a rarity in commerce, and may contain ingredients fatal to the properties of certain varieties of bronze. The difficulty of preparing alloys of definite composition is increased when scrap is remelted with new metal, unless great care is taken to keep scrap of a given quality separate from other varieties; such old metal is also liable to contain iron and other foreign metals mechanically mixed with it.

Zinc in small quantity added to copper and tin has often a beneficial influence, as in casting, for instance, the metal runs thinner, fills up the moulds, and is freer from pin-holes. The zinc probably acts favourably in uniting with any oxygen which may be present, forming oxide of zinc. If the addition of zinc much exceeds what is required for this purpose, the alloy will be weaker, although harder, and the colour will more or less resemble that of brass. For this reason the amount of zinc should not exceed 2 per cent when high tenacity and elasticity are desired as important factors in the alloy.

Lead alloys very imperfectly with bronze, showing a great tendency to liquate out on cooling, the greater portion being found in the lower part of the casting. A small quantity of lead is said to make the alloy more malleable and denser. The peculiar patina of a velvety black colour found on old Chinese bronzes is probably due to the presence of lead.

Iron, in certain amounts, affects the properties of bronze very beneficially. It hardens the alloy and increases its resistance to wear in cases where the bronze is subjected to considerable friction, as in machinery bearings. Such alloys are paler in colour and more difficult to melt than with copper and tin alone. In small quantity iron increases the tenacity of bronze.

In 1858 Parker noticed that the addition of phosphorus during the melting together of copper and tin improved the physical properties of bronze in some respects, and this addition was eventually introduced into bronze manufacture with very successful results. The action of phosphorus in phosphor-bronze is to exert a refining influence on the mixed metals, rather than to form a definite alloy of copper, tin, and phosphorus, since many samples of phosphor-bronze of excellent quality contain but the merest traces of phosphorus. During the melting of copper and tin a certain amount of oxides is formed, which, being soluble in the molten metals, exerts a weakening influence on the alloy by preventing that intimate union of the constituent metals which is necessary to give the strength, toughness, and durability for which some varieties of bronze are noted.

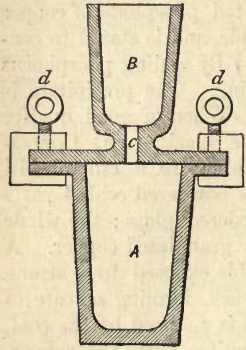
Phosphorus has a strong affinity for oxygen, and when brought in contact with metallic oxides, such as those of tin and copper, reduces them, forming oxide of phosphorus. Now this oxide has an acid character, and readily unites with metallic oxides, which are generally basic, to form a fusible slag. This slag, being lighter than the metal and very fusible, floats on the surface and may be readily removed. If the requisite amount of phosphorus be added for the above purpose, the oxygen will be completely removed; if any excess of the required quantity be added, such phosphorus will unite with the alloy, and may become a source of weakness instead of strength. Some metallurgists have thought that the beneficial action of phosphorus is due to its combination with the copper and tin, but such is not probably the case, since, if more than a small quantity be added, the metal is hardened at the expense of toughness; but the alloy still possesses considerable tenacity, and, for special purposes, may be useful. Also, as mentioned above, chemical analysis proves that the strongest bronzes contain only minute quantities of phosphorus. Montefiori-Levi and Künzel, who introduced phosphor-bronze as a material to be used in construction in 1871, state that, besides the deoxidising influence of phosphorus on metals, it performs another very important function. In many copper-tin alloys the copper forms the only crystallised constituent, tin crystallising with great difficulty; and the alloy, in consequence of the different physical condition of the two metals, is not as solid as it would be if both the components were crystallised. Phosphorus has the power of imparting to tin a crystalline nature, which enables it to form with copper a more intimate union, and thus produce a more homogeneous alloy.

If more phosphorus be used than is necessary for the purpose of deoxidation of the metals, the resulting body may be considered an alloy of crystallised phosphor-tin with copper. The question of producing various qualities of phosphor-bronze depends not so much upon the quantity of phosphorus as upon the correct proportioning of the various ingredients. The alloys are generally prepared by adding a specially prepared phosphor-copper or phosphor-tin (both these metals being sometimes used at the same time) to the bulk of the copper to be treated (see also p. 192).

§ 64. **Phosphor-copper** may be prepared in a variety of ways. (1) By dropping phosphorus upon molten copper in a crucible an alloy rich in phosphorus is obtained, forming an extremely hard, steel-gray, fusible compound. (2) By reducing phosphate of copper with charcoal, or charcoal and carbonate of soda. (3) By heating a mixture of 4 parts bone-ash, 1 part charcoal, and 2 parts granulated copper at a moderate temperature. The melted phosphide of copper separates on the bottom of the crucible, and is stated to contain 14 per cent of phosphorus. (4) By adding phosphorus to copper-sulphate solution and boiling. The precipitate is dried, melted, and cast into ingots. When of good quality and in proper condition it is quite black. (5) Copper-phosphide is easily prepared by adding to a crucible 14 parts sand, 18 parts bone-ash, 4 parts powdered coal, 4 parts sodium carbonate, and 4 parts powdered glass; the whole being intimately mixed with 9 parts granulated copper. A lid is then luted on and the crucible exposed to a strong heat. The sand acts on the bone-ash, forming silicate of lime. The liberated phosphoric acid is reduced by the coal, and the phosphorus thus set free unites with the copper. (6) Montefiori-Levi and Künzel prepare phosphor-copper by putting sticks of phosphorus into crucibles containing molten copper. To avoid a too ready combustion the sticks of phosphorus are previously coated with a firm layer of copper, by placing them in a solution of copper sulphate. (7) By strongly heating in a crucible an intimate mixture of bone-ash, copper oxide, and charcoal, phosphor-copper is produced.

§ 65. **Phosphor-tin.**—(1) When finely divided tin is heated in the vapour of phosphorus, a silvery-white, very brittle phosphide is obtained, containing about 21 per cent of phosphorus. (2) When phosphorus is dropped into molten tin combination takes place with the formation of a white phosphide, containing about 15 per cent of phosphorus. (3) By placing a bar of zinc in an aqueous solution of chloride of tin, a spongy mass of metallic tin is obtained; by placing this moist tin on the top of sticks of phosphorus in a crucible, pressing down tightly, and then exposing to a gentle heat until the flames of burning phosphorus cease, a crystalline mass of phosphor-tin is obtained.

The following excellent plan is adopted in some works for the manufacture of phosphor-copper and phosphor-tin. In a cast-iron crucible A, Fig. 27, is placed the requisite quantity of phosphorus, then the top crucible B is tightly joined to A by means of screw clamps *d d*. The molten metal is poured into B and runs through the opening *c* on to the phosphorus. The vaporised phosphorus can only escape by passing through the molten metal, and is thus almost completely absorbed.



Scale of 1/16

FIG. 27.

§ 66. Very small quantities of sulphur, arsenic, and antimony render bronze brittle, $\frac{1}{10}$ per cent being sufficient to modify its properties.

The physical properties of bronze depend upon the composition, mode of manufacture, mechanical treatment, and rate of cooling after heating. [1] Riche has examined a series of copper-tin alloys with regard to fusibility, liquation, and changes of density resulting from certain operations. The alloys having the chemical formulæ $SnCu_3$ and $SnCu_4$ are the only ones which melt and solidify without decomposition, and their melting points lie between 600° and 700° C.; all other alloys of tin and copper undergo liquation at the moment of solidification.

The several alloys, in quantities of 500 to 700 grammes, were fused for ten hours in tubular moulds, and the top and bottom portions of the castings were analysed. Another portion of each of the melted alloys was stirred during solidification, and the portion which last remained fluid was poured off and likewise analysed. The following table gives the results :—

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[1] *Ann. Chim. Phys.* (4) vol. xxx. p. 351.

RICHE'S TABLE OF COPPER-TIN ALLOYS

	Composition.		Percentage of tin.		Percentage of tin in the portion last solidified.	Physical properties.
	Cu.	Sn.	top.	bottom.		
1. $CuSn_5$	9·73	90·27	87·87	92·9	98·50	Tin-gray, soft as tin, non-crystalline.
2. $CuSn_3$	15·21	84·79	83·15	78·90	96·99	Tin-gray, crystallising by slow cooling.
3. $CuSn_2$	21·21	78·79	74·97	77·4	94·40	Tin-gray, crystallised, moderately hard.
4. $CuSn$	34·99	65·01	55	80	82·83	Whitish-gray, crystalline, and brittle.
5. Cu_2Sn	51·84	48·16	...	...	50·42	Bluish-gray like zinc, crystalline, very brittle.
6. Cu_3Sn	61·79	38·21	37·29	37·66	37·37	Bluish, fine-grained, pulverisable in a mortar.
7. Cu_4Sn	68·28	31·72	30·44	30·83	30·91	White, laminar, brittle as glass.
8. Cu_5Sn	72·91	27·09	27·15	26·78	27·76	White, with yellow reflex, crystalline, very hard.
9. Cu_6Sn	76·31	23·69	23·37	23·69	25·17	Yellowish, very hard, fine-grained, malleable at dull red heat.
10. Cu_7Sn	79·02	20·98	21·0	21·32	24·85	Like No. 9.
11. Cu_8Sn	81·15	18·85	18·88	18·56	24·6	Like No. 9.
12. $Cu_{10}Sn$	84·33	15·67	15·18	15·18	20·06 24·50	Distinctly yellow.
13. $Cu_{15}Sn$	89·00	11·00	...	...	13·1	Gun-metal.

The specific gravity of these alloys is best determined by filing off portions from the upper and lower ends of the casting, and taking the mean of the two densities. In alloys rich in tin expansion takes place (that is to say, the specific gravity of the alloy is less than the mean specific gravities of the two metals) up to the proportion $CuSn_2$; alloys richer in copper exhibit contraction, which is small in the alloy $SnCu_2$, then suddenly becomes very great, attains its maximum in $SnCu_3$ and then gradually diminishes, the greatest density, 8·91, is found in the alloy $SnCu_3$, even the more cupriferous alloys exhibiting lower densities, *e.g.* gun-metal, 8·84.

The hardness of the alloys, reckoning from pure tin, increases with the proportion of copper down to CuSn. This and all the more cupriferous alloys down to Cu_5Sn are extremely brittle, and from this alloy the hardness diminishes as the proportion of copper increases. The hardness of the alloy consisting of 66·66 parts tin and 33·33 parts copper is said to be the same as that of pure copper.

The alloy $SnCu_3$ is distinguished from all the rest by several characters; it presents the same homogeneous composition after repeated fusion, is peculiar in colour, has the highest density, exhibits the greatest degree of contraction, and is so brittle that it may be pounded in a mortar.

Bronzes containing from 18 to 22 per cent of tin, such as are used for making wind-instruments, have their density increased by heating and suddenly plunging into cold water; but on again raising them to a red heat and allowing them to cool slowly the density is lowered, but not to the value it had before the sudden cooling. By mechanical treatment, such as simple compression or the blow of a coining-press, followed by sudden or slow cooling, the density of these alloys is increased, more also (from 8·775 to 8·952) by pressure and sudden cooling than by pressure and slow cooling (from 8·782 to 8·854). These bronzes, therefore, are affected by sudden cooling and by annealing in the opposite manner to steel. They cannot be worked at ordinary temperatures, because they break too easily; they are likewise brittle at a red heat, and between 100° and 200° C. But at temperatures a little below dull redness they may be forged like iron, easily hammered out into thin plates, and reduced from $\frac{1}{2}$ inch to $\frac{1}{16}$ inch thickness by rolling. This property renders them available for the fabrication of gongs, which in external appearance and sonorous qualities, as well as in chemical composition, are identical with the famous Chinese instruments. By the same treatment in the warm state these bronzes are, moreover, rendered denser, and more easily brought to any given density, than by similar treatment when cold.

Alloys containing 94 to 88 per cent copper and 6 to 12 per cent tin can be rolled and hammered at ordinary temperatures, and are not increased in density by slow or sudden cooling; if they are at the same time subjected to mechanical treatment their specific gravities are slightly increased. A bronze containing 6 per cent tin had its density increased from 8·924 to 8·932, by 72 blows alternating with 24 annealings; and by similar treatment, substituting quick for slow cooling, the density was increased from 8·928 to 8·935.

According to the amount of tin present in bronze the colour varies between red and white, and with a large excess of tin it becomes steel-gray. Generally speaking, tin whitens copper more than zinc, 73 parts copper and 27 parts tin forming a white alloy. Alloys containing 89 per cent of copper and upwards are red or reddish-yellow, 88 per cent copper and 12 per cent tin is orange-yellow, and the alloy containing 85 per cent of copper is pure yellow; from 85 to 74 per cent copper the yellow colour becomes fainter, and disappears with 72 per cent of copper. Alloys with 1 to 2 per cent of tin are malleable, ductile, and tough, but less so than pure copper. With a greater content of tin the metal becomes less malleable, an alloy with 5 per cent tin can only be worked hot, cracking when hammered cold. Alloys with 15 per cent tin cannot be forged hot or cold. The greatest strength, as previously remarked, being found in bronze used as gun-metal containing about 90 per cent copper and 10 per cent tin. From practical experience it has been found that the greatest strength is obtained by so working as to produce the crystals of the alloy as small as possible, even the kind of mould in which the casting is effected exerting an influence upon the grain, and through this upon the strength. Articles must be cast at a higher temperature in iron moulds than in sand moulds, 1600° C. being required in the former, while 1400° C. will suffice for the latter, especially for large castings.

§ 67. The following table of copper-tin alloys was prepared for the United States Board by the Committee on Alloys (*Report*, vol. i. 1879, p. 390).

Properties of Copper-tin Alloys

No.	Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity	Colour.	Fracture.	Tenacity in lbs. per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Hardness (Mallet and Calvert and Johnson).	Order of malleability (Mallet).	Order of fusibility (Mallet).	Conductivity for heat. Silver =100.	Conductivity for electricity. Silver =100.	Authority.	Remarks.
		Cu.	Sn.	Cu.	Sn.													
1	..	100	0	..	..	8·791*a* 8·874*b*	Copper-red	fibrous	27,800	..	30·08	..	..	..	..	..	U.S.B.	*a.* Specific gravity of bar. *b.* Specific gravity of turnings from ingot.
2	..	100	0	..	..	8·667	tile-red	earthy	55,104	1	..	10	2	16	..	..	Ml.	..
3	..	100	0	..	..	8·921	..	..	..	..	..	..	..	..	..	93·16	Ma.	..
4	..	100	0	..	..	..	..	..	..	..	..	301	..	..	81·1	..	C. J.	..
5	..	100	0	..	..	8·794	..	..	..	..	..	..	..	..	..	..	Cr.	..
6	..	100	0	..	..	8·921	..	..	..	..	..	..	..	..	..	..	Mar.	Cast copper.
7	..	100	0	..	..	8·952	..	..	..	..	..	..	..	..	..	..	Mar.	Sheet copper.
8	..	100	0	..	..	..	..	..	..	..	..	..	..	..	73·6	79·3	We.	..
9	..	100	0	..	..	8·672	..	..	24,252	..	..	..	..	..	..	..	Wa.	Mean of nine samples.
10	..	98·59	1·41	..	..	..	..	..	..	..	100·1	..	..	..	..	62·46	Ma.	..
11	$SnCu_{96}$	98·1	1·9	97·89	1·9	8·564	red	vesicular	..	..	..	..	..	..	..	..	U.S.B.	Defective bar.
12	..	98·04	1·96	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Can be forged like copper.
13	..	98	2	..	..	..	..	..	..	..	..	..	..	..	..	..	La.	Ram-rods for guns.
14	..	97·5	2·5	..	..	8·511	red	vesicular	..	..	..	..	..	..	..	..	U.S.B.	Defective bar.
15	..	96·97	3·03	..	..	..	..	..	..	..	..	..	..	..	..	..	W.	Resists action of hydrochloric acid.
16	$SnCu_{48}$	96·27	3·73	96·06	3·76	8·649	reddish-yellow	vesicular	32,000	..	70·3	..	..	..	..	..	U.S.B.	..

17	..	96	4	..	..	8·947	..	..	..	..	..	..	..	..	..	..	Ri.	Annealed and compressed.
18	..	95	5	..	..	..	golden-yellow	..	..	..	..	..	..	..	..	..	W.	Hard, malleable.
19	..	94·1	5·9	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Pieces of machines.
20	..	94	6	..	..	8·939	..	..	..	..	..	..	..	..	..	..	Ri.	Specific gravity after repeated tempering.
21	..	93·98	6·02	..	..	..	..	..	..	..	..	..	..	..	..	19·68	Ma.	..
22	$SnCu_{25}$	93·17	6·83	..	..	8·82	..	..	..	..	..	602·8	..	..	..	..	C. J.	..
23	$SnCu_{24}$	92·8	7·2	..	..	8·694	reddish-yellow	vesicular	28,540	..	21·9	..	..	..	..	..	U.S.B.	..
24	..	92·5	7·5	..	..	8·684	reddish-yellow	,,	27,900	..	43·2	..	..	..	..	..	U.S.B.	..
25	..	92	8	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Bronze for medals.
26	..	91·75	8·25	..	..	..	..	..	..	..	..	..	..	..	..	..	W.	Shows separation of metals when examined with a lens.
27	..	91·74	8·26	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	English ordnance.
28	..	91·7	8·3	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Ordnance metal.
29	..	91·66	8·33	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Eight-pounder guns.
30	$SnCu_{20}$	91·9	8·51	..	..	8·793	..	..	..	..	..	639·58	..	..	..	..	C. J.	..
31	..	91·3	8·7	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Toothed wheels.
32	..	90·91	9·09	..	..	..	..	..	32,093	..	..	..	..	..	..	..	Mus.	Prussian ordnance.
33	..	90·9	9·1	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Ordnance metal.
34	..	90·73	9·27	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	French ordnance.
35	..	90·1	9·9	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	..
36	..	90	10	90·27	9·58	8·669	grayish-yellow	earthy	26,860	..	18	..	..	..	..	..	U.S.B.	Compressed ordnance bronze.

Properties of Copper-tin Alloys—*Continued*

No.	Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity	Colour.	Fracture	Tenacity in lbs. per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Hardness (Mallet and Calvert and Johnson).	Order of malleability (Mallet).	Order of fusibility (Mallet).	Conductivity for heat. Silver =100.	Conductivity for electricity. Silver =100.	Authority.	Remarks.
		Cu.	Sn.	Cu.	Sn.													
37	..	90	10	..	..	8·875	..	..	..	..	..	..	..	..	..	..	De.	After repeated compression.
38	..	90	10	..	..	8·935	..	..	..	..	..	..	..	..	..	..	Ri.	Railway-car bearings.
39	..	90	10	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Ordnance metal.
40	..	89·3	10·7	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Small bar, cast in iron mould.
41	..	89·29	10·71	..	..	8·953	..	..	37,688	..	..	..	..	..	..	..	Wa.	Small bar, cast in clay mould.
42	..	89·29	10·71	..	..	8·313	..	..	25,783	..	..	..	..	..	..	..	Wa	Mean of 12 gun-heads.
43	..	89·29	10·71	..	..	8·353	..	..	26,011	..	..	..	..	..	..	..	Wa.	Ordnance metal.
44	..	89·23	10·77	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	..
45	$SnCu_{15}$	89	11	..	..	8·84	..	..	..	..	..	..	..	..	..	..	Ri.	..
46	$SnCu_{15}$	88·97	11·03	..	..	8·825	..	..	..	..	..	772·92	..	..	..	..	C. J.	Mean of 83 gun-heads.
47	..	88·89	11·11	..	..	8·523	..	..	..	..	..	..	..	..	..	..	Wa.	..
48	..	88·39	11·61	..	..	..	..	..	..	..	..	..	..	..	..	12·1	Ma.	Gun-metal.
49	..	88	12	..	..	..	..	..	..	..	..	..	..	..	..	..	La.	..
50	..	87·65	12·35	..	..	..	..	..	..	..	..	..	..	..	..	10·15	Ma.	..
51	..	87·5	12·5	..	..	8·648	grayish-yellow	earthy	31,100	..	7·3	..	..	..	..	..	U.S.B.	..
52	..	86·8	13·2	..	..	..	..	..	..	..	..	..	..	..	..	..	W.	..
53	$SnCu_{12}$	86·57	13·43	87·15	12·73	8·681*a* 8·943*b*	mottled white and yellow	finely vesicular	29,430	..	13·09	..	..	..	..	..	U.S.B.	*a*. Specific gravity of bar. *b*. Specific gravity of fine turnings.

54	..	86·21	13·79	..	..	8·87	..	..	..	..	..	..	..	..	..	..	W.	Densest of all alloys? (Riche.)
55	..	86	14	..	..	..	..	..	..	..	..	..	..	..	..	..	W.	Axle-tree bed, Seraing locomotive.
56	..	85·71	14·29	..	..	..	..	..	44,071	..	..	..	..	..	..	..	Mus.	..
57	..	85·09	14·91	..	..	..	..	..	..	..	..	..	..	..	..	8·82	Ma.	..
58	$SnCu_{10}$	84·33	15·67	..	..	8·87	..	..	..	..	..	..	..	..	..	..	Ri.	..
59	..	84·3	15·68	..	..	8·832	..	..	..	..	..	..	916·66	..	..	..	C. J.	..
60	..	84·29	15·71	..	..	8·561	reddish-yellow	finely crystalline	36,064	2	..	8	6	15	..	..	Ml.	..
61	..	84	16	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Carriage-wheel boxes.
62	..	83·3	16·7	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Jewellers' punches.
63	$SnCu_9$	82·81	17·19	..	..	8·462	reddish-yellow	finely crystalline	34,048	3	..	5	7	14	..	..	Ml.	..
64	..	82·5	17·5	..	..	8·792	reddish-gray	finely crystalline	36,200	..	0·32	..	..	..	..	..	U.S.B.	Strongest of series.
65	..	82	18	..	..	8·927	..	..	..	..	..	..	..	..	..	..	R.	Annealed and tempered.
66	$SnCu_8$	81·15	18·85	..	..	8·86	..	..	..	..	..	..	..	..	..	..	Ri.	..
67	$SnCu_8$	81·1	18·9	..	..	8·459	yellowish-red	finely crystalline	39,648	4	..	4	10	13	..	..	Ml.	..
68	..	..	..	80·43	19·57	8·953	..	..	..	..	..	..	..	..	..	..	Th.	Chinese gong.
69	..	80	20	..	..	8·7	..	..	..	..	..	..	..	..	..	..	Bo.	Bells of Reichenhall 300 years old.
70	..	80	20	..	..	..	..	..	35,739	..	..	..	..	..	..	..	Mus.	..
71	..	80	20	..	..	8·85	..	..	..	..	..	..	..	..	..	..	Ri.	Annealed and tempered.
72	..	80	20	..	..	8·955	..	..	..	..	..	..	..	..	..	..	Ri.	After repeated compression.
73	..	80	20	80·95	18·84	8·74	reddish-gray	finely granular	32,980	..	0·4	..	..	..	..	..	U.S.B.	..
74	..	79·2	20·8	..	..	8·927	..	..	..	..	..	..	..	..	..	..	Ri.	Annealed and tempered.
75	$SnCu_7$	79·02	20·98	..	..	8·90	..	..	..	..	..	..	..	..	..	..	Ri	..
76	$SnCu_7$	78·97	21·03	..	..	8·728	yellowish-red	vitreous conchoidal	30,464	5	..	3	11	12	..	..	Ml.	..

Properties of Copper-tin Alloys—*Continued*

No.	Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity	Colour.	Fracture.	Tenacity in lbs. per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Hardness (Mallet and Calvert and Johnson).	Order of malleability (Mallet).	Order of fusibility (Mallet).	Conductivity for heat. Silver =100.	Conductivity for electricity. Silver =100.	Authority.	Remarks.
		Cu.	Sn.	Cu.	Sn.													
77	..	78	22	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	..
78	..	77·5	22·5	..	..	8·917	pinkish-gray	finely-granular	24,650	..	0·03	..	..	..	..	..	U.S.B.	..
79	$SnCu_6$	76·82	23·68	76·64	23·24	8·565	..	smooth	22,010	..	0·02	..	..	..	..	..	U.S.B.	..
80	$SnCu_6$	76·31	23·69	..	..	8·91	..	..	..	..	..	..	..	..	..	..	Ri.	..
81	$SnCu_6$	76·29	23·71	..	..	8·75	bluish-red	vitreous	21,728	0	..	2	12	11	..	..	Ml.	..
82	..	76·2	23·8	..	..	9·1 ?	..	..	..	..	..	..	..	..	..	..	Bo.	Church bell in Reichenhall 600 years old.
83	..	75·2	24·8	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Swiss clock bells, brittle.
84	..	75	25	..	..	..	..	..	..	..	..	..	..	..	..	..	W.	..
85	$SnCu_5$	72·91	27·09	..	..	8·87	reddish-white	..	..	..	..	..	..	..	..	..	Ri.	..
86	$SnCu_5$	72·9	27·1	..	..	8·965	..	..	..	..	..	broke	..	..	..	..	C. J.	..
87	$SnCu_5$	72·8	27·2	..	..	8·575	bluish-red	con-choidal	10,976	0	..	1	13	10	20·7	..	Ml.	..
88	..	72·5	27·5	..	..	8·925	reddish-white	con-choidal	6,493	..	·008	..	..	..	..	..	U.S.B.	..
89	..	70	30	69·84	29·89	8·932	white	con-choidal	5,585	..	·008	..	..	..	..	..	U.S.B.	..
90	..	68·82	31·18	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Mirror of telescope.
91	$SnCu_4$	68·28	31·72	..	..	8·80	..	..	..	..	..	..	..	..	..	..	Ri.	..
92	$SnCu_4$	68·27	31·73	..	..	8·948	..	..	..	..	..	broke	..	..	..	..	C. J.	..
93	$SnCu_4$	68·25	31·75	68·58	31·28	8·938	white	con-	1,620	..	..	..	..	..	15·5	..	U.S.B.	..

94	$SnCu_4$	68·21	31·79	..	..	8·40	ash-gray	conchoidal	1568	0	..	6	14	9	..	..	Ml.	..
95	..	68·21	31·79	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Mirror metal.
96	..	67·5	32·5	..	..	8·907	white	conchoidal	2536	..	·009	..	..	..	..	..	U.S.B.	..
97	..	66·67	33·33	..	..	..	steel-gray	..	..	..	..	..	..	..	..	..	W.	Hard, uniform.
98	..	66·67	33·33	..	..	..	..	..	1017	..	..	..	..	..	..	..	Mus.	..
99	..	65	35	65·34	34·47	8·947	bluish-gray	..	2201	..	·002	..	..	..	..	..	U.S.B.	..
100	..	62·5	37·5	..	..	8·956	dark gray	radiated crystalline	1561	..	·001	..	..	..	..	..	U.S.B.	..
101	$SnCu_3$	61·79	38·21	..	..	8·954	..	..	..	..	..	broke	..	..	49·4	..	C. J.	..
102	$SnCu_3$	61·79	38·21	..	..	8·96	..	..	..	..	..	..	..	..	..	..	Ri.	..
103	$SnCu_3$	61·71	38·29	..	..	8·97	dark gray	rough, stony	688	..	·003	..	..	..	..	..	U.S.B.	Greatest density, weakest.
104	$SnCu_3$	61·69	38·31	..	..	8·539	dark gray	tabular crystalline	1120	0	..	7	16	8	..	..	Ml.	..
105	..	60	40	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	White bell-metal.
106	..	57·5	42·5	..	..	8·781	light gray	stony	1377	..	·001	..	..	..	..	..	U.S.B.	..
107	Sn_5Cu_{12}	56·32	43·68	56·7	43·17	8·682	light gray	,,	1455	..	·003	..	..	..	..	..	U.S.B.	..
108	..	52·5	47·5	..	..	8·643	light gray	,,	..	..	·001	..	..	..	..	..	U.S.B.	Weakest under transverse stress.
109	$SnCu_2$	51·84	48·16	..	..	8·57	..	..	..	..	..	..	..	..	..	..	Ri.	..
110	$SnCu_2$	..	..	..	..	8·512	..	..	..	..	..	..	..	..	..	..	Cr.	..
111	$SnCu_2$	51·83	48·17	..	..	8·533	..	..	..	..	..	broke	..	..	42·8	..	C. J.	..
112	$SnCu_2$	51·8	48·2	51·62	48·09	8·56	light gray	..	2555	..	·003	..	..	..	..	..	U.S.B.	Remarkable for liquation.
113	$SnCu_2$	51·75	48·25	..	..	8·416	gray-white	vitreous conchoidal	3808	0	..	9	15	7	..	..	Ml.	..
114	..	50	50	..	..	..	..	..	725	..	..	..	..	..	..	..	Mus.	..
115	..	50	50	..	..	8·79	bluish-white	..	..	..	..	..	..	..	..	..	W.	Very slightly malleable.
116	Sn_7Cu_2	47·95	52·05	47·61	52·14	8·442	grayish-white	fine grain	1525	..	·003	..	..	..	..	..	U.S.B.	..
117	..	47·5	52·5	..	..	8·446	grayish-white	crystalline	2407	..	·003	..	..	..	..	..	U.S.B.	..

No.	Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity	Colour.	Fracture.	Tenacity in lbs. per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Hardness (Mallet and Calvert and Johnson).	Order of malleability (Mallet).	Order of fusibility (Mallet).	Conductivity for heat. Silver =100.	Conductivity for electricity. Silver =100.	Authority.	Remarks.
		Cu.	Sn.	Cu.	Sn.													
118	Sn_2Cu_3	44·67	55·33	..	..	8·3	grayish-white	..	..	..	..	..	..	..	..	..	Ri.	..
119	Sn_3Cu_3	44·63	55·37	44·52	55·28	8·312	grayish-white	crystalline	3010	..	·003	..	..	..	..	..	U.S.B.	..
120	..	42·5	57·5	..	..	8·437	grayish-white	,,	2098	..	·006	..	..	..	..	..	U.S.B.	..
121	Sn_3Cu_4	41·74	58·26	42·38	57·30	8·302	grayish-white	,,	3910	..	·007	..	..	..	..	..	U.S.B.	..
122	..	40	60	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	White bell-metal.
123	Sn_5Cu_6	39·2	60·8	38·37	61·32	8·182	grayish-white	crystalline	2820	..	·005	..	..	..	..	..	U.S.B.	..
124	..	37·5	62·5	..	..	8·101	grayish-white	,,	2400	..	·004	..	..	..	..	..	U.S.B.	..
125	SnCu	34·99	65·01	..	..	8·12	..	..	..	..	..	..	..	..	..	..	Ri.	..
126	SnCu	34·98	65·02	..	..	7·992	..	..	..	..	..	broke	..	..	41·5	..	C. J.	..
127	SnCu	..	..	..	..	8·072	..	..	..	..	..	..	..	..	..	..	Cr.	..
128	SnCu	34·95	65·05	34·22	65·8	8·013	grayish-white	crystalline	3371	..	·005	..	..	..	..	..	U.S.B.	..
129	SnCu	34·92	65·08	..	..	8·056	grayish-white	tabular crystalline	3136	0	..	11	9	6	..	..	Ml.	..
130	..	33·33	66·67	..	..	..	white	..	..	..	..	..	..	..	..	..	W.	Brittle, uniform.
131	..	32·5	67·5	..	..	7·931	grayish-white	crystalline	2322	..	·014	..	..	..	..	..	U.S.B.	..
132	Sn_4Cu_3	28·72	71·28	25·85	73·8	7·918	grayish-white	,,	1648	..	·011	..	..	..	..	..	T.	..
133	..	27·5	72·5	..	..	7·915	grayish-white	,,	4380	..	·018	..	..	..	..	..	T.	..
134	..	25	75	..	..	7·813	bluish-white	,,	..	..	..	..	..	..	..	..	W.	..

135	Sn_5Cu_3	24·38	75·62	23·35	76·29	7·835	grayish-white	finely crystalline	6775	..	·03	..	..	..	..	..	T.	..
136	..	22·5	77·5	..	..	7·774	grayish-white	finely crystalline	5000	..	·12	..	..	..	..	..	T.	..
137	..	21·74	78·26	21·38	77·63	7·53	whitish	..	..	..	..	..	..	..	..	..	W.	Yellow, greenish white.
138	Sn_2Cu	21·21	78·79	..	..	7·738	..	..	..	..	..	135·42	..	..	43·1	..	C. J.	..
139	Sn_2Cu	21·21	78·79	..	..	7·74	..	..	..	..	..	..	..	..	..	..	Ri.	..
140	Sn_2Cu	21·18	78·82	20·25	79·63	7·77	grayish-white	crystalline	4337	..	·06	..	..	..	..	..	T.	..
141	Sn_2Cu	21·15	78·85	..	..	7·387	grayish-white	,,	8736	0	..	12	8	5	..	..	Ml.	..
142	Sn_5Cu_2	17·68	82·32	..	..	7·652	..	..	..	..	..	..	..	..	..	..	Cr.	..
143	..	17·5	82·5	..	..	7·69	grayish-white	crystalline	2816	..	·2	..	..	..	..	..	T.	..
144	..	16·4	83·6	..	..	..	..	..	..	..	..	..	..	..	..	12·76	Ma.	..
145	Sn_3Cu	15·21	84·79	..	..	7·53	..	..	..	..	..	..	..	..	..	..	Ri.	..
146	Sn_3Cu	15·21	84·79	..	..	7·606	..	..	..	..	..	104·17	..	..	42·3	..	C. J.	..
147	Sn_3Cu	15·19	84·81	15·08	84·62	7·657	grayish-white	crystalline	6520	..	·92	..	..	..	..	..	T.	..
148	Sn_3Cu	15·17	84·83	..	..	7·447	grayish-white	coarsely-crystalline	6944	0	..	13	15	4	..	..	Ml.	..
149	..	12·5	87·5	..	..	7·543	grayish-white	crystalline	3798	..	4·71	..	.	..	..	..	T.	..
150	Sn_4Cu	11·86	88·14	..	..	7·558	..	..	..	..	..	95·81	..	..	40·6	..	C. J.	..
151	Sn_4Cu	11·84	88·16	11·49	88·47	7·552	grayish-white	crystalline	6380	..	7·08	..	..	..	..	..	T.	..
152	Sn_4Cu	11·84	88·16	..	..	7·5	..	..	..	..	..	..	..	..	..	..	Ri.	..
153	Sn_4Cu	11·82	88·18	..	..	7·472	grayish-white	coarsely-crystalline	6944	8	..	14	4	3	..	..	Ml.	..
154	Sn_5Cu	9·73	90·27	..	..	7·517	..	..	..	..	..	83·33	..	..	39·6	..	C. J.	..
155	Sn_5Cu	9·73	90·27	..	..	7·52	..	..	..	..	..	..	..	..	..	..	Ri.	..
156	Sn_5Cu	9·7	90·3	8·57	91·39	7·49	grayish-white	granular	6450	..	23·47	..	..	..	..	..	T.	..
157	Sn_5Cu	9·68	90·32	..	..	7·442	grayish-white	earthy	3360	6	..	15	3	2	..	..	Ml.	..
158	..	9·09	90·91	..	..	7·472	..	..	..	..	..	..	..	..	..	..	W.	Slightly malleable.
159	..	7·5	92·5	..	..	7·417	grayish-white	granular	6096	..	40·06	..	..	..	..	..	U.S.B.	..
160	..	6·43	93·57	..	..	..	..	..	..	..	..	..	..	..	..	12·03	Ma.	..

PROPERTIES OF COPPER-TIN ALLOYS—*Continued*

No.	Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity	Colour.	Fracture.	Tenacity in lbs. per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Hardness (Mallet and Calvert and Johnson).	Order of malleability (Mallet).	Order of fusibility (Mallet).	Conductivity for heat. Silver =100.	Conductivity for electricity. Silver =100.	Authority.	Remarks.
		Cu.	Sn.	Cu.	Sn.													
161	$Sn_{12}Cu$	4·29	95·71	3·72	96·31	7·36	grayish-white	granular	4780	..	56·77	..	..	..	..	..	U.S.B.	..
162	..	2·5	97·5	..	..	7·342	grayish-white	fibrous	5600	..	121·9	..	..	..	..	..	U.S.B.	..
163	$Sn_{48}Cu$	1·11	98·89	·74	99·02	7·305	grayish-white	,,	3650	..	133·9	..	..	..	..	..	U.S.B.	..
164	$Sn_{96}Cu$	·56	99·44	·32	99·46	7·299	grayish-white	,,	4475	..	208·8	..	..	..	..	..	U.S.B.	..
165	Sn	0	100	..	..	7·293	,,	,,	3500	..	219·8	..	..	..	..	..	U.S.B.	..
166	..	0	100	..	..	7·291	white	fibrous	6040	7	..	16	1	1	..	..	Ml.	..
167	..	0	100	..	..	7·297	..	..	2122	..	..	..	..	..	..	..	Wa.	..
168	..	0	100	..	..	7·294	..	..	..	..	..	..	..	..	..	11·45	Ma.	..
169	..	0	100	..	..	7·305	..	..	..	..	..	..	..	..	..	..	Cr.	..
170	..	0	100	..	..	..	..	..	..	..	..	27	..	..	42·2	..	C. J.	..
171	..	0	100	..	..	..	..	..	..	..	..	..	..	..	15·2	17	We.	..

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Ri.—Riche. *Annales de Chimie*, 1873, vol. xx. pp. 351-419.

U.S.B.—"Report of Committee on Metallic Alloys appointed by United States Board, to test Iron, Steel, etc."

T.—Thomas Tomson. *Annales de Chimie*, 1814, vol. lxxxix. pp. 46-58.

W.—Watt's *Dictionary of Chemistry.*

Wa.—Major Wade, United States Army. "Report on Experiments on Metals for Cannon," *Phil.* 1856.

We.—Weidemann. *Phil. Mag.* 1860, vol. xix. pp. 243, 244.

Notes on Table.—In the foregoing table the figures of order of ductility, hardness, and fusibility are taken from Mallet's experiments on a series of sixteen alloys, the figure 1 representing the maximum and 16 the minimum of the property. The ductility of the brittle metals is represented as 0.

The relative ductility given in the table of the alloys experimented on by the U.S. Board is the proportionate extension of the exterior fibres of the pieces tested by torsion, as determined by the autograph strain diagrams. It will be seen that the order of ductility differs widely from that given by Mallet.

The figures of relative hardness, on the authority of Calvert and Johnson, are those obtained by them by means of an indenting tool. The figures are on a scale in which cast-iron is rated at 1000. The word "broke" in this column indicates that the alloy opposite which it occurs broke under the indenting tool, showing that the relative hardness could not be measured but was considerably greater than that of cast-iron.

The figures of specific gravity show a fair agreement among the several authorities in the alloys containing more than 35 per cent of tin, except those given by Mallet, which are in general very much lower than those by all the other authorities. In the alloys containing less than 35 per cent of tin there is a wide variation among all the different authorities, Mallet's figures, however, being generally lower than the others. Several of the figures of specific gravity have been selected from Riche's results of experiments on the effects of annealing, tempering, and compression, which show that the latter especially tends to increase the specific gravity of all the alloys containing less than 20 per cent tin to about 8·9. This result is due merely to the closing up of the blowholes, thus diminishing the porosity. The specific gravity of 8·953 was obtained by Major Wade by casting a small bar in a cold iron mould from the same metal which gave a specific gravity of only 8·313 when cast in the form of a small bar in a clay mould. The former result is exceptionally high, and indicates the probability that every circumstance of the melting, pouring, casting, and cooling was favourable to the exclusion of the gas which forms blowholes, and to the formation of a perfectly compact metal.

The figures of tenacity given by Mallet, Musschenbroek, and Wade agree with those found in the experiments as closely as could be expected from the very variable strengths of alloys of the same composition which have been found by all experimenters.

Mallet's figure for copper 24·6 tons, or 55,104 lbs., is certainly very much too high for cast copper; the piece which he tested was probably rolled or perhaps drawn into wire. Haswell's *Pocket-book* gives the following as the tensile strength of copper; the names of the authorities are not given:—

Copper, wrought	34,000	lbs. per square inch.
,, rolled	36,000	,, ,,
,, cast (American)	24,250	,, ,,
,, wire	61,200	,, ,,
,, bolt	36,800	,, ,,

The strength of gun-bronze, as found in the guns, is not given in the table, which is designed to compare the various authorities on the tenacities of the alloys only as cast under ordinary conditions, and not when compressed, rolled, or cast under pressure.

COMMERCIAL VARIETIES OF BRONZE

§ 68. **Gun-metal.**—With regard to this alloy it should be stated that iron and steel have almost entirely superseded it for making guns, yet a consideration of its properties for this purpose may not be out of place in this work. For the construction of ordnance it is necessary to employ a metal which is capable of resisting great and sudden pressures, for it is calculated that in firing an ordinary cannon a pressure of 2000 atmospheres is suddenly developed; and it will readily be seen from this that a metal of peculiar strength and endurance is required for such a purpose. A vast number of experiments have been made to endeavour to arrive at the best proportions of copper and tin to employ in making an alloy for guns, but no uniform standard has been adopted for all countries, each preferring a separate mixture. It should be borne in mind that two alloys of exactly the same chemical composition may have very different properties conferred upon them by different mechanical treatment, and unless we know the manner in which a gun is finally completed, we cannot produce an article of similar properties by simply using the proportions given by chemical analysis. This is probably the reason why, in the guns of different countries and of different periods of history, a uniform standard has not been employed. The following table will illustrate this point:—

	Copper.	Tin.	Iron.	Zinc.	Lead.
English ordnance . .	91·74	8·26	...	...	...
,, ,, . .	91·8	8·20	...	...	...
8-pounder guns . .	91·66	8·33	...	...	...
Prussian ordnance .	90·91	9·09	...	...	...
French ,, . .	90·73	9·27	...	...	...
,, ,, . .	90·09	9·9	...	...	...
American compressed ordnance	90	10	...	...	...

	Copper.	Tin.	Iron.	Zinc.	Lead.
American compressed ordnance	90·27	9·73	...	...	...
Russian ordnance (1819)	88·61	10·7	·69	...	...
Swiss ,,	88·93	10·38	·11	·42	·06
Chinese ,,	77·18	3·42	1·16	5·02	13·22
,, ,,	93·19	5·43	1·38	...	...

The proportions best suited for guns vary from 8 to 11 parts copper to 1 of tin; the best of these proportions, according to Karsten, is 9 parts copper to 1 of tin. The alloy of 11 parts copper to 1 of tin appears uniform after sudden cooling to the unassisted sight, but when examined with a lens it appears to be composed of striated faces of a reddish alloy, mixed with a white one. If it be still more rapidly solidified by pouring into thick iron moulds, an alloy is obtained which appears perfectly uniform, even under the lens. When cooled in water, after continued strong ignition, it remains uniform; but if suffered to cool slowly after continued ignition, it becomes variable in composition, like that which has been slowly cooled after fusion. Hence the alloy which is uniform at the melting point, and likewise at a strong red heat, separates into two different alloys when slowly cooled. The large mass of a cannon cannot be cooled, even by moulds which conduct heat well, suddenly enough to prevent the separation of two distinct alloys, the one that is richer in copper solidifying first, while that which is richer in tin containing 82·3 per cent copper and 17·7 per cent tin, partly rises to the top and partly sinks into the mould.

Gun-metal must possess a considerable degree of hardness and elasticity, as in firing the gun the cartridge strikes several times against the sides, and if the metal yields permanently to the pressure thus exerted upon it, the bore gradually loses its cylindrical form after a time, and its accuracy for shooting at a given object is largely destroyed. Moreover, in firing a cannon a large quantity of gas is generated, which has a more or less corrosive action on metal, so that it is advisable to use that alloy which is least affected by such gases, provided it has the requisite strength and endurance. In short, the properties desired for good gun-metal are: that it should be very tenacious, sufficiently hard and elastic to resist distortion, indifferent to the ordinary chemical influences, thinly liquid when melted, and capable of settling down solid in the moulds when cast.

Modern practice in producing gun-metal has resulted in the exclusive use of copper and tin, as combining the above advantages in the highest degree, and although the addition of a third metal may be advantageous in strengthening one particular property, it is injurious to the required properties taken as a whole. The addition of a little phosphorus is useful in special cases, but the quantity added must be very small. In fact the phosphorus is used only as a purifier, and the amount remaining in the bronze is almost infinitesimal, and cannot be reckoned as a factor in the final alloy. In old guns many foreign ingredients are found, such as nickel, cobalt, lead, iron, bismuth, arsenic, etc.; but in many cases the amounts are so small that they may be looked upon as adventitious impurities, and not as purposely introduced into the mixture for alloying. With regard to lead, zinc, and iron, these metals have doubtless been intentionally added in certain cases, with a view to producing a given effect. The other metals mentioned are occasional impurities found in commercial copper, which in former times was much more impure than the varieties obtainable at the present time.

The term "gun-metal," as understood at the present time by many engineers and brassfounders, is not confined exclusively to alloys of copper and tin, as zinc and other metals are very frequently added; and, in fact, the term seems to be applied to any alloy in which copper largely predominates, and which possesses considerable strength and toughness. Several of the triple alloys of copper, tin, and zinc possess many excellent properties, which fit them for parts of machinery and for anti-friction metals. These will be referred to under the head of "Machine Brasses." The following table will show the composition of a few of these alloys:—

No.	Copper.	Tin.	Zinc.	Colour.
I	92	2	6	Pale red.
II	90	8	2	Reddish-yellow.
III	84	5	11	Yellow.
IV	83	5	12	,,
V	80	15	5	Pale yellowish-pink.
VI	80	5	15	Yellow.
VII	75	5	20	Greenish-yellow.

No. I is tough, malleable, and tenacious. No. II is hard, somewhat unyielding, and easily broken. Nos. III and IV work well under the file and chisel. No. V is hard but somewhat malleable. No. VI is hard and resisting, tough, and works fairly well with the file and chisel. No. VII is hard and easily broken, but may be filed.

The alloys are hard and brittle when the copper is less than 66 per cent of the mixture; and when the copper is reduced to 50 per cent the alloys are extremely hard and brittle. The addition of a little lead improves the above alloys for turning and filing. A sample of so-called "gun-metal," stated by the user to be very strong and durable, and used for crown-wheel escapements, gave on analysis—

Copper	87·85
Zinc	5·07
Tin	4·96
Lead	1·84
Iron	·28
	100·00

An alloy prepared by Mr. Stirling, and tried in the Arsenal of Woolwich, has a resistance to flexion much greater than that of ordinary bronze; it contains—

Copper	87
Tin	8·7
Zinc	4·3
	100·0

The above alloy is difficult to obtain in a sound and homogeneous state.

Bell-metal

§ 69. The various alloys used in the manufacture of bells consist essentially of copper and tin, but in some cases other metals are added in small quantity either for cheapness, or to produce a desired quality of sound. The additional metals chiefly used are zinc, lead, iron, and sometimes bismuth, silver, antimony, and manganese. The following table will show a few of the proportions employed :—

	Copper.	Tin.	Zinc.	Lead.	Iron.	Silver.	Bismuth.	Antimony.
Musical bells	84	16	...	...	...	...	...	...
Sleigh bells .	84·5	15·4	...	...	...	...	...	·1
Gongs . .	82	18	...	...	...	...	...	...
House bells .	80	20	...	...	...	...	...	...
,, ,,	78	22	...	...	...	...	...	...
Large bells .	76	24	...	...	...	...	...	...
Swiss clock bells	74·5	25	...	·5	...	...	...	...
Old bell at Rouen	71	26	1·8	1·2	...	...	...	...
Clock bells .	72	26·56	...	...	...	1·44	...	...
Alarm bell at Rouen	75·1	22·3	1·0	...	...	1·6	...	...
Tam-tam .	79·0	20·3	...	·52	...	·18	...	...
Japanese kara kane	64	24	9	...	3	...	...	...
Japanese kara kane	70	19	3	8	...	...	...	...
Japanese kara kane	61	18	6	12	3	...	...	...
White table bells	17	80	...	...	...	...	3	...
White table bells	...	87·5	...	...	...	...	...	12·5
Small bells	40	60	...	...	...	...	...	...

In addition to the above alloys, small bells are made of ordinary brass, especially when a wrought pattern is required on the outside for the purpose of ornamentation; but the sound from such bells is of inferior quality. Mr. P. M. Parsons states that manganese-bronze is peculiarly adapted for large bells. The advantages claimed are, that bells cast from it possess the same or greater sonorousness, with a more mellow tone, and are at the same time so tough that they cannot be cracked like bells made of ordinary bell-metal, which is made brittle in order to acquire the requisite sonorousness. Good bell-metal should give a pure full sound, the quality of which varies with the purpose for which it is designed. The sound may be modified by chemical composition, but it is also dependent upon the mode of manufacture. The alloy should be hard, homogeneous, fine-grained, and strong. The colour of bell-metal of normal composition, containing from 76 to 80 per cent copper and 24 to 20 per cent tin, is yellowish-gray, and when very slowly cooled from a red heat is very hard, difficult to file, sonorous, brittle, and exhibits a fine-grained fracture when broken. When heated to redness and suddenly cooled by plunging into cold water it becomes moderately soft, and capable of being easily filed, turned, and otherwise worked. It may be hardened by heating to redness and allowing to cool slowly. At a temperature not far below redness it is malleable. An alloy of 80 per cent copper and 20 per cent tin, when slowly cooled after fusion, exhibits a dingy-gray striated appearance and is very brittle. If suddenly chilled in cold water from a low red heat it becomes yellowish-gray and extensible. During the ignition, if the temperature be raised too high, white globules of an alloy, rich in tin, separate out, so that bell-metal appears to be resolved into two alloys at a temperature below its melting point, which on slow cooling reunite and form a brittle alloy, but remain separated if the cooling be too sudden.[1]

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[1] Watt's *Dic.* vol. ii. p. 44.

The tone of a bell is influenced materially by its size and shape, by the thickness of the metal, and by the ratio of the height to the diameter. The skill of the bellfounder is not only exercised in finding the best composition to be employed, but also in determining the exact shape and size for a required note and tone, which is of special importance in chimes. Some dinner-bells are made of two halves, having a clapper on each side, the two having different sounds, of a major or minor third interval, and thus forming an agreeable combination when struck.

Table bells are sometimes preferred to be white, which is effected by casting in white metal, as given in the preceding table, or the ordinary alloys are whitened by the addition of tin or nickel. For boiling white, the bells are first highly polished and then placed in a hot bath of water with cream of tartar added, and a layer of granulated tin placed between each row of bells in the bath. The bath is kept at a temperature of 212° F. for two or three hours, then the bells are removed, washed in clean water, and finally polished with chamois leather. Many bells are now nickel plated.

The melting and casting of bell-metal is similar to that of bronze. The copper is generally melted first, the tin subsequently added, and the whole vigorously stirred to promote intimate mixture. When scrap is used along with new metal, the copper and scrap are melted together, and the new tin added as before. In casting small bells no *odd-side* is required as in ordinary brass casting. The patterns, with the convex side upwards, are placed on a board, and a casting frame placed over them; parting material (generally brick-dust) is then dusted over them to prevent the casting sand sticking to the patterns. A layer of raw sand, pounded very fine in a mortar, is then laid on the patterns as a first coat, and the frame filled up with ordinary sand. The sand is well rammed down, first with the hands, then with a mallet, and sometimes with the feet. A board is then placed on the top, and the frame inverted; one side of the mould is now completed. The *peg* frame of the mould is now fixed on the top of the other, and the inside of the bell pattern dusted. Sand is then added and rammed in as before, a board placed on the top, and the double frame inverted. It is then beaten with a mallet to loosen the pattern, and the board taken off, thus exposing the patterns, which are now carefully taken off the cores, as they are termed, which are then dusted with a mixture of charcoal and flour. The frame is then screwed together, leaned against the spilling hearth, and the metal poured in. The caster usually makes about five moulds before pouring, this being termed a *heat.*

Small bells are now also cast in iron moulds.

It has often been observed that bells cast from metal which has been repeatedly remelted acquire a disagreeable tone, and this has been attributed to the formation of metallic oxides and the solution of these oxides by the molten metal. If such metal be treated with a substance capable of exerting a deoxidising influence, such as phosphorus, silicon, manganese, magnesium, etc., a complete reduction of the metallic oxides takes place, the liberated oxygen uniting with the reducing agent added and passing into the slag. Deoxidising agents must be used very sparingly, otherwise the excess will enter into combination with the alloy and may be a greater evil than the one it is employed to remedy.

Chinese tam-tams and gongs are characterised by a strong penetrating sound, which is conferred by the peculiar mechanical treatment they are made to undergo. As soon as the plates are well solidified they are taken from the mould, raised to a cherry-red heat in a furnace, then inserted between iron discs to prevent warping, and the whole plunged into cold water and allowed to cool. After this treatment they are found sufficiently malleable to be worked under the hammer.

For large bells the metal is melted in a reverberatory furnace, and the molten alloy ought to be exposed to the heat for several hours, which produces a more homogeneous texture and less crystallisation. If any zinc is to be added to such an alloy, it is advisable to add it in the form of brass, calculating of course the quantity of copper it contains. The relative quantity of the metals forming the alloy can be calculated and mixed to this arrangement; but the melting operation has an influence upon the strength of the metal. The more volatile constituents are volatilised to a greater extent than the copper, so that the founder takes proofs before casting and adds the constituent which is deficient. The trial sample is taken in a small iron ladle, the metal broken when cold, and the quality determined by the character of the fractured surface, tenacity, etc.

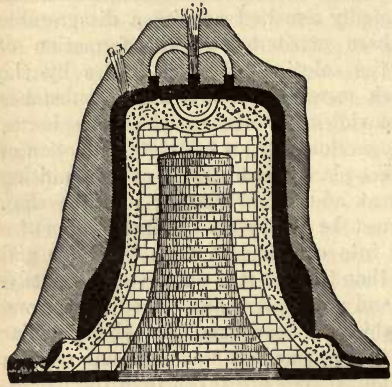

FIG. 28.

The following description of the casting of a large bell is taken from Overman's *Founders' Guide*: "In Fig. 28 a mould is represented as it is sunk in the pit for casting. The core is built in brick upon an iron platform, which is to have 'snugs' in case the mould is made above ground. This brick core is covered with three-fourths of an inch or one inch thick of hair-loam, and the last surface-washing is given by a finely-ground composition consisting of clay and brick-dust. This latter is mixed with an extract of horse-dung, to which is added a little sal-ammoniac. Upon the core the 'thickness' is laid in loam sand, but the 'thickness' is again washed with fine clay to give it a smooth surface. Ornaments which have been previously moulded, either in wax, wood, or metal, are now pasted on by means of wax, glue, or any other cement. If the ornaments are of such a nature as to prevent the lifting of the cope without them—for the cope cannot be divided — the ornaments are fastened to the 'thickness' by tallow, or a mixture of tallow and wax. A little heat given to the mould will melt the tallow, after which the ornaments adhere to the cope, from which they may be removed when the cope is lifted off the core. The 'thickness' is to be well polished, and as no coal can be used for parting, the whole is slightly dusted over with wood-ashes. The parting between the core and the 'thickness' is also made with ashes. The cope is laid on at first by means of a paint-brush, the paint consisting of clay and ground bricks made thin by horse-dung water. This coating is to be thin and fine; upon it hair-loam, and finally straw-loam is laid. The crown of the bell is moulded over a wood pattern after the spindle is removed. The iron staple for the hammer is set in the core, into the hollow left by the spindle. It projects into the thickness so as to be cast into the metal. The facing of the mould ought to be finished when the cope is lifted off. Small defects may occur, and are, if not very large, left as they are; the excess of metal in those places is chiselled off after the bell is cast. All that can be done in polishing the facing of the mould is to give it a uniform dusting of ashes. When the mould is perfectly dry it is put together for casting. The core may be filled with sand if preferred, but there is no harm done if it is left open, for bell-metal does not generate much gas, and there is no danger of an explosion. The cope is in some measure secured by iron, but its chief security is in the strong, well-rammed sand of the pit. The cast-gate is on the top of the bell, either on the crown or, if the latter is ornamented, on one side of it. Flow-gates are of no use here, the metal is to be cleaned before it enters the mould; there is no danger of sullage."

Speculum Metal

§ 70. This is a perfectly white alloy which admits of a beautiful polish, used formerly for mirrors but now only used for such purposes as the construction of mirrors for optical instruments, and even here they are being gradually displaced by glass mirrors. Its typical composition is represented by the formula Cu_4Sn, containing 66·6 per cent of copper and 33·4 per cent of tin. The speculum metal of Lord Ross's large telescope is composed of 68·21 copper and 31·79 tin. This alloy is of a brilliant white lustre and has a specific gravity of 8·811; it is nearly as hard as steel, and brittle. The speculum is cast 6 feet in diameter and 5¼ inches thick, and weighs upwards of three tons. The casting of this mirror was only effected after repeated failures. A mould was made whose bottom consisted of a wrought-iron ring, packed full of hoop-iron laid edgeways, so close that air but no metal could escape through the crevices; this bottom was turned convex on a lathe, true to the concavity of the speculum; it was then placed upon a level floor and enclosed by a sand dam left open from above. The metal was melted in cast-iron crucibles, because wrought-iron or clay would have injured the alloy. The cast was carried while hot into the annealing oven, which was previously heated to a red heat, and left there sixteen weeks to cool.

Good speculum metal should be pure white, of a fine-grained structure, perfectly sound and homogeneous when cast, and sufficiently tenacious to stand grinding and polishing without rupture. It should contain 65 to 68 per cent of copper to comply with all these requisites. The following table exhibits different varieties:—

	Copper.	Tin.	Zinc.	Arsenic.	Lead.	Other metals.
English alloy .	66·6	33·4	...	...	...	...
Ross's alloy . .	68·21	31·79	...	...	...	...
Ancient mirror .	62	32	...	...	6	...
Richardson's alloy	65·3	30	·7	2	...	2 silver.
Sallit's alloy .	64·6	31·3	...	...	...	4·1 nickel.
Chinese alloy .	80·83	11·67	...	...	...	8·5 antimony.

CHAPTER IV

MACHINE BRONZES OR BRASSES

§ 71. Under this general term will be included various alloys employed for different parts of machinery, such as bearings, and parts subjected to great friction. These alloys very frequently contain ingredients other than copper and tin. They must be sufficiently hard to resist wear, capable of being easily cast into various shapes, worked with the file and turning tools, and otherwise prepared by mechanical treatment for the uses for which they are designed.

For the bearings of large axles and shafting, especially those which revolve with great rapidity, alloys containing 80 to 90 per cent of copper are used. These alloys are capable of being forged at a red heat, a property often required for their manufacture into different shapes. Some alloys are required to possess great strength, so as to resist sudden shocks without yielding; others are required to offer little frictional resistance under a heavy load when in contact with other metals.

§ 72. ALLOYS SUITABLE FOR BEARINGS

	Copper.	Tin.	Zinc.
Ordinary bearings .	84·5	13·3	2·2
,, ,, .	83·6	12·6	3·8
Heavy ,, .	84	12	4
,, ,, .	77	9	14
Main ,, .	75	4	21
Locomotive axles .	86	...	14
,, ,,	82	10	8
Moderately hard axles	70	22	8
Hard axles . .	82	16	2
Very hard axles .	89	...	11

For white alloys for bearings see p. 229.

Different manufacturers hold different views as to the best mixtures to employ for a given purpose, as will be seen by the very varied proportions given in the previous table for bearings. Moreover, an alloy used for a special purpose will not possess the same properties under all circumstances, and the mixture must be modified to suit local requirements. It has been shown in the preceding pages how greatly even small quantities of impurities will affect metals, so that an alloy containing foreign ingredients will have its molecular structure disturbed by their presence, and this has doubtless led some persons to alter their mixtures, when they should have looked to the purity of the constituent metals employed. Even chemical analysis, however, will not always reveal the reason why a certain alloy possesses certain properties, as the qualities may have been conferred by special mechanical treatment. The mode of melting, mixing, and casting will also influence the final result.

The following table is intended to show the composition of various alloys, and may serve as a general guide :—

	Copper.	Tin.	Zinc.	Lead.	Other metals.
Eccentric rings .	90	7·7	2·3	...	...
,, ,, .	66	15·5	18·5	...	...
Pumps . . .	84	7	9	...	...
,, . . .	34	50	16	...	...
Kingston valve .	84·2	10·5	5·3	...	...
Cocks and glands .	81	3	13	3	...
Paddle wheel pins .	76·8	17·4	5·8	...	...
Sluice cock-way .	81	...	19	...	...
Propeller-blades and boxes	57	14	29	...	...
Hydraulic pumps .	81	...	19	...	...
Propeller-shaft liner .	80	5·4	14·6	...	...
White-metal bush for propeller	5	26	69	...	...
Cog-wheels . .	91	...	9	...	...
Steam whistles .	80	17	3	...	...
Stuffing boxes . .	86	11	3	...	...
Mechanical instruments	82	13	5	...	...
Piston rings . .	84	2·9	8·3	4·8	...
Stevenson's socket alloy	19	31	19	31	...
Sterro-metal for pumps	55	6	22·5	...	Iron 16·5
Valve-balls . .	87	12	...	...	Antimony 1

The following tables represent the mixtures employed by a large engineering firm, using scrap and new metal :—

	Bearing brasses.	Eccentric pumps.	Pumps.	Cocks and glands.	Sluice cock-way.
Copper .	38	38	38	38	38
Spelter .	1	1	4	6	9
Lead .	...	...	...	1½	...
Tin . .	7	4	3	1½	...
Old metal	54	57	55	53	53

	Bearing brasses.	Eccentric pumps.	Kingston valve.	Paddle wheel pins.	Propeller blades and boxes.
Copper	56	28	112	56	16
Tin	8½	6½	14	12½	4
Spelter	2½	7½	...	3½	8
Old metal	45	70	7	40	84

	Heavy bearings.	Heavy bearings.	Main bearings.	Propeller shaft liner.
Ingot-copper	16	16	16	56
Block-tin	2¼	3	2 – 3	6
Zinc	¾	...	...	...
Old brass	...	13	32	50

Hydraulic Pumps.

Ingot-copper	14 lbs.
Zinc	1½ ,,
Yellow brass	3½ ,,
Or spelter	1¾ ,,

White Metal Bush for Propeller Shaft.

Ingot-copper	6 lbs.
Tin	32 ,,
Spelter	84 ,,

Phosphor-Bronze

§ 73. This is an alloy of copper and tin containing a small quantity of phosphorus and other ingredients in definite proportions, the general properties of which have been already discussed, so that the mode of manufacture and the suitability of the metal for machinery and engineering purposes need only be here stated. It is prepared by melting and mixing copper and tin in the usual way, and adding a certain quantity of phosphor-copper, or phosphor-tin, or both, and well incorporating the ingredients by vigorous stirring. A new plumbago pot is used so as to avoid contamination from other metals, and charcoal or coke added as a covering to prevent unnecessary oxidation. For large castings the moulds are thoroughly dried and dressed with a mixture of blacklead and water. Small work is cast in ordinary green sand. In cooling from the molten state it passes directly from the liquid to the solid condition, without passing through an intermediate pasty state. If remelted it does not sensibly alter in composition, except that when phosphorus is present in notable quantity, that element is slightly decreased by volatilisation. If the alloy be poured into the moulds at too high a temperature, a certain amount of separation of the constituents occurs as in ordinary bronze, so that it is advisable to pour phosphor-bronze only just before the setting takes place. This is effected by adding ingots or runners to the molten metal, and when the metal no longer melts these, but adheres to them, it is a sign that pouring should take place.

For rolling; drawing into wire, rods, and tubes; making bolts, springs, screws, etc., the tin should not exceed 4 to 5 per cent, and the phosphorus less than $\frac{1}{10}$ per cent, the remainder being copper. It can be forged into firearms of various descriptions.

For pinions, valves, steam and boiler fittings, pumps and general ornamental castings the tin is about 7 per cent, and the phosphorus varies between ·15 and ·25 per cent. This is a strong, tough metal, and much harder than the preceding alloy.

For axle-bearings, slide-valves, bushes, cog-wheels, and all parts of machinery exposed to much friction, a metal of great hardness and strength is required, and should contain from 90 to 91 per cent of copper, 9 to 8 per cent of tin, and from $\frac{3}{4}$ to 1 per cent of phosphorus.

When the amount of phosphorus is much greater than the above, the alloys are harder, less malleable and tough, and in cases where hardness is the chief requisite, can be made to rival steel in this respect. With upwards of 4 per cent phosphorus the bronze is useless.

Phosphor-bronze possesses the advantage of not becoming crystalline under the action of repeated shocks and bends, and is therefore well adapted for wire rope. It resists the action of sea-water better than copper, and also the corrosive action of water in mines better than iron or steel.

The following table published by the Phosphor-Bronze Company shows the results obtained with various axle-bearings, but as the compositions of their phosphor-bronzes are omitted, the table is robbed of its chief value as a standard of comparison.

RESULTS OBTAINED WITH VARIOUS AXLE BEARINGS

Kind of bearing.	Composition in 100 parts alloy.	Comparative cost of 100 kilos. of bearings inclusive of melting expenses, loss, etc.	1 Kilo. bearing metal runs.			Cost of bearing metal per waggon with 4 bearings per 100 kilometres.	Names of railroads where used.
			German miles.	Kilometres.	Wear per 1000 kilos. for 4 bearings.		
		marks.			grammes.	s. gr.	
Gun-metal . .	83 copper, 17 tin	$260\frac{2}{10}$	12,052	90,390	$11\frac{60}{100}$	0·301	Austrian Railway.
,, ,, . .	82 ,, 18 ,,	$260\frac{8}{10}$	13,320	99,900	$10\frac{1}{100}$	0·260	Grand Central Belge.
White metal . .	3 copper, 90 tin, 7 antimony	$298\frac{68}{100}$	9,104	78,280	$14\frac{64}{100}$	0·395	Austrian Railway.
,, ,, . .	5 copper, 85 tin, 10 antimony	$293\frac{40}{100}$	11,750	88,145	$11\frac{35}{100}$	0·331	Niederschlesisch-Märkische Bahn.
Lead composition .	84 lead, 16 antimony	$118\frac{56}{100}$	10,338	81,280	$12\frac{30}{100}$	0·145	Austrian Railway.
Phosphor-Bronze .	...	350	57,226	429,200	$2\frac{33}{100}$	0·081	Grand Central Belge.
Gun-metal on brake cars	82 copper, 18 tin	$260\frac{8}{10}$	1,218	9,134	$109\frac{48}{100}$	2·844	,, ,,
Phosphor-Bronze on brake cars	...	350	14,320	107,410	$9\frac{31}{100}$	0·325	,, ,,

From a number of drop tests made at the Pittsburg Works, the following results were obtained :—

DROP TESTS

(*The fractions of inches stated in the table represent the permanent set of the test bar after the blow.*)

METALS TESTED.	NUMBER OF BLOWS.																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Phosphor-Bronze, XIV. B.	$\frac{3}{16}$ a	$\frac{1}{4}$ a	$\frac{3}{8}$ a	$\frac{7}{16}$ a	$\frac{1}{2}$ a	$\frac{5}{8}$ a	$\frac{11}{16}$ a	$\frac{3}{4}$ a	$\frac{25}{32}$ a	$\frac{13}{16}$ d	$\frac{7}{8}$ g	$\frac{15}{16}$ g	1÷ f	$\overset{\frown}{\frac{3}{4}}$ a	$\frac{11}{16}$ a	$\frac{9}{16}$ d	$\frac{1}{2}$ f	$\frac{3}{8}$ Broke. f		
Phosphor-Bronze, 6×17.	$\frac{3}{16}$ a	$\frac{3}{8}$ a	$\frac{1}{2}$ a	$\frac{5}{8}$ a	$\frac{23}{32}$ a	$\frac{13}{16}$ a	$\frac{15}{16}$ a	1″ a	$\overset{\frown}{\frac{7}{8}}$ a	$\frac{3}{4}$ a	$\frac{9}{16}$ a	$\frac{1}{2}$ a	$\frac{3}{8}$ a	$\frac{1}{4}$ a	— a	3 *foot blows.* 1″ b	$\overset{\frown}{—}$Broke. a			…
Rolled Charcoal Scrap Iron, best quality.	$\frac{1}{4}$ a	$\frac{1}{2}$ 1	$\frac{11}{16}$ g	$\frac{29}{32}$ g	$1\frac{3}{32}$ g	$\overset{\frown}{\frac{7}{8}}$ a	$\frac{9}{16}$ a	$\frac{7}{16}$ a	$\frac{3}{16}$ a	— a	8 *foot blows.* $1\frac{5}{16}$ a	$\overset{\frown}{—}$Broke. d			…	…	…	…	…	…
Best Charcoal Fire Box Plate Iron.	$\frac{5}{32}$ a	$\frac{9}{32}$ a	$\frac{7}{16}$ b	$\frac{9}{16}$ c	$\frac{11}{16}$ c	$\frac{13}{16}$ c	$\frac{29}{32}$ c	1″ c	$\overset{\frown}{\frac{13}{16}}$ a	$\frac{5}{8}$ a	$\frac{7}{16}$ d	$\frac{1}{4}$ Broke. f			…	…	…	…	…	…
The same, cut *cross-wise* off plate.	$\frac{3}{16}$ b	$\frac{3}{8}$ c	$\frac{9}{16}$ c	$\frac{3}{4}$ Broke. c		…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
Charcoal Tank Plate Iron.	$\frac{1}{8}$ a	$\frac{9}{32}$ c	$\frac{7}{16}$ c	$\frac{9}{16}$ c	$\frac{3}{4}$ Broke. c		…	…	…	…	…	…	…	…	…	…	…	…	…	…
Best Forged Charcoal Iron.	$\frac{3}{16}$ d	$\frac{3}{8}$ f	$\frac{9}{16}$ fe	$\frac{11}{16}$ f	$\frac{13}{16}$ f	$\frac{15}{16}$ fb	$1\frac{1}{16}$ fc	$\overset{\frown}{\frac{13}{16}}$ d	$\frac{11}{16}$ Broke. f			…	…	…	…	…	…	…	…	…

Weight of drop 148 lbs.; height of stroke 12 inches, except where otherwise stated; distance between the supports 4 inches; striking face of drop, a blunted wedge-shape; test-bars 6 inches long, 2 inches wide, and ½ inch thick. The letters indicate the state of the surface of the test-bar on the side upon which the blow has been given: a, sound; b, slight cracks at edge; c, cracks at edge increase in size; d, slight cracks in middle of test-bar; e, cracks in middle increase in number; f, cracks in middle increase in size; g, remains unaltered; —, straight; ⌒, test-bar reversed.

At the Imperial Austrian Polytechnic Institution in Vienna experiments were executed by Professor R. Jenney with Phosphor-Bronze bars, showing the following results:—

Degree of elasticity.	Resistance at point of elasticity.	Resistance at point of rupture.
9875	13·74 kilos. per square millimetre or 19·857 lb. per square inch.	40·40 kilos. per square millimetre or 58,383 lb. per square inch.

In the Imperial Arsenal at Vienna experiments were made by Colonel Uchatius, giving the following results:—

	Absolute resistance.	Point of elasticity.	Stretch in percentage.
			Per cent.
Phosphor-Bronze	5,600 kilos. per square c.m. or 81,795 lb. per square inch.	3,800 kilos. per square c.m. or 54,915 lb. per square inch.	1·6
Krupp's cast steel as used for guns	5,000 kilos. per square c.m. or 72,258 lb. per square inch.	1,000 kilos. per square c.m. or 14,450 lb. per square inch.	11·0
Ordnance bronze	2,200 kilos. per square c.m. or 31,792 lb. per square inch.	385 kilos. per square c.m. or 5,562 lb. per square inch.	15·0

SILICON-BRONZE

§ 74. In 1881 M. Weiller of Angoulême performed a series of experiments with phosphor-bronze wire, to test its suitability for telegraphic and telephonic conductors, and his results went to show that it possessed a conductivity one-third that of copper, but 2½ times that of iron and steel. The conductivity not being sufficient for telegraphic purposes, he invented silicon-bronze, which is an alloy of copper and tin containing silicon. He thus obtained a wire presenting the same resistance to rupture as phosphor-bronze wire, but with a much higher degree of conductivity, rendering it applicable for telegraph purposes. Mr. W. H. Preece states that phosphorus has a most injurious influence on the electrical conductivity of bronze, and that silicon-bronze is far superior, and has entirely replaced phosphor-bronze for telegraphic purposes. It is also important to note that, although wires made from this alloy are very much lighter than ordinary wires, they are of equal strength; and it is affirmed that, if broken, they will not fall to the ground as the ordinary wires do; but by reason of their high elasticity they spring back and coil up close to the standards. The same is also true of phosphor-bronze. The following table shows the comparative properties of different wires :—

Description of wire.	Tensile strength in tons per square inch.	Resistance per mile in ohms.	Relative conductivity.
Pure copper . . .	17·78	33·1	100
Silicon-bronze (telegraph)	28·57	34·5	96
,, ,, (telephone)	48·25	103	34
Phosphor-bronze ,,	45·71	124	26
Swedish-iron, galvanised	22·86	216	16
Bessemer-steel, ,,	25·40	249	13
Siemens-Martin steel .	26·67	266	12

E. van der Ven[1] conducted a series of experiments to determine the value of phosphor-bronze and silicon-bronze for electrical purposes, chiefly as materials for telephone wires, and came to the conclusion that phosphor-bronze has about 30 per cent of the conductivity of copper, and silicon-bronze about 70 per cent, while that of steel has only 10·5 per cent the conducting power of copper. Comparing their tensile strengths with that of steel, he finds that a steel wire, 2 millimetres diameter, with quadruple security, and the conventional "sag" of 0·7 millimetre, can have a stretch from pole to pole of 130 metres. The stretch of a phosphor-bronze wire, 1 millimetre diameter, under the same conditions would be 106 metres, and for silicon-bronze 91 metres. These alloys, with a diameter of 1·18, and 0·77 millimetres respectively, have the same electrical resistance as a steel wire 2 millimetres diameter.

Silicon-bronze is valuable on account of its great strength and tenacity, high conductivity, and resistance to corrosion by atmospheric influences; and is therefore one of the very best mediums for transmission of electrical force. It can be made nearly as strong as steel, and yet possess treble its conductivity. The manufacture of this alloy has been greatly improved since its introduction, the latest kinds possessing less conductivity for electricity, but a higher tensile strength, which allows the wire to be more tightly stretched, and the supports wider apart. Wires of silicon-bronze are largely used on the continent for telephone purposes, and will stand the force of violent storms remarkably well, which is in some measure due to the small diameter of the conductor. In one case, at Rheims, a line having a span of 1000 feet was exposed to the action of the wind blowing directly across it, and stood the test admirably. The Italian General Telephone Company have employed silicon-bronze wires for some time without an accident occurring. Railway engineers have proved its efficacy for resisting a weight of snow in cold and hilly districts. When the wires have been covered with snow, and "sagged" considerably, they have immediately assumed their normal deflections when the snow has been removed. The poles of an Austrian railway company, using silicon-bronze, are from 328 to 720 feet apart across flat country, and from 160 to 500 feet apart in hilly districts. [1] Mr. Robey states that the blizzard, which did so much damage to telegraph wires in the United States in 1887, did not break those made of silicon-bronze.

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[1] Musée Teyler, and Electrotech. Zeitsch. 1883.

Silicon-copper and silicon-bronze are made, according to Weiller, the inventor of these combinations, in the following manner. He recommends the following proportions: potassium silico-fluoride 450 parts by weight, powdered glass 600 parts, common salt 250 parts, carbonate of soda 75 parts, carbonate of lime 60 parts, and dried chloride of calcium 500 parts. The mixture is heated in a covered plumbago crucible to a temperature a little below the point when they begin to act on each other, when the mixture is added to the molten copper or bronze, as the case may be; the reduced silicon combining with the metal or alloy.

The action of silicon on copper and bronze is similar to that of phosphorus. It acts as a deoxidiser, and the silica formed being an acid, is a valuable flux for any metallic oxides remaining unreduced. Silicon also enters into chemical combination with the alloy.

MANGANESE-BRONZE

§ 75. This is a new combination introduced by Mr. P. M. Parsons, to whom the author is indebted for much of the following information.[2] Copper and iron unite at high temperatures in various proportions, forming alloys of great hardness, and when the iron is present in certain proportions the tenacity and elasticity of the copper is increased. The same remarks apply to brass and bronze. It should be stated, however, that the above properties are acquired at the expense of ductility and toughness. The effect of iron being so decided, led some metallurgists to try the influence of manganese by reducing oxide of manganese with carbon in the presence of copper. Mr. Stirling and Mr. A. Parkes both used manganese to alloy with copper, brass, and other alloys. Mr. Everitt of Birmingham has introduced manganese into yellow-metal for sheathing and similar purposes.

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[1] Paper read before the Cleveland Inst. of Engineers, December 1888.

[2] *Brit. Assoc. Report*, 1883.

No comparative experiments as to the strength, hardness, and ductility, or other qualities of these alloys, appear to have been published. The effect of manganese is to add somewhat to the ductility and toughness of copper alloys and allow copper, zinc, etc., of commoner quality to be used for definite purposes. In 1876 Mr. Parsons introduced his method of manufacturing manganese brass and bronze by mixing ferro-manganese with copper, and using this triple alloy for making various copper alloys, such as brass and bronze.

§ 76. **Cupro-Manganese.**—Copper and manganese unite in various proportions, forming alloys which may be red like copper, or silvery-white in colour, depending upon the amount of manganese present. They possess considerable hardness and tenacity, some are very ductile, and more fusible than ordinary bronze. They are distinguished by the property of soundness when cast into moulds, the castings being free from blow-holes. The great difficulty in producing alloys containing much manganese is owing to the great affinity that this metal has for oxygen, and the high temperature required for the reduction of manganese from its oxides, which are used as a source of the metal. This renders the production of homogeneous alloys, with a required amount of manganese, very difficult.

Pure oxide of manganese is not found in nature, at any rate only in rare cases: the most frequently occurring ore is *pyrolusite*, generally containing oxides of other metals, which are reduced along with the manganese and enter into the composition of the alloy. Pyrolusite is used for the manufacture of chlorine gas, and the bye product can be used to obtain oxide of manganese in a comparatively pure form, and this is employed for the production of *cupro-manganese*, by reducing it in contact with copper.

The copper is finely granulated, mixed with charcoal and dry oxide of manganese, in alternate layers in a plumbago crucible, and the whole covered with a thick layer of charcoal powder. A lid is then placed on to prevent admission of air, the crucible put into a wind-furnace, and exposed to the highest temperature of the same for some hours. The oxide is gradually reduced to the metallic state, and alloys with the copper forming cupro-manganese, which settles to the bottom of the crucible. When the operation is completed the pot is removed from the furnace, and the contents vigorously stirred with an iron rod to thoroughly incorporate the ingredients and produce a homogeneous alloy. The metal thus obtained is silver-white in colour, resembling German silver.

Cupro-manganese is considerably altered in composition by repeated remelting, the manganese being so readily oxidised, and as metallic manganese is not a commercial article, the metal cannot be added to make up the loss in the same way as zinc is added to brass. Moreover, the crucible is strongly attacked by oxide of manganese, which has a strong affinity for silica, forming a liquid slag. Alloys containing from 15 to 30 per cent of manganese have a white colour, are hard, very tough, and can be forged and rolled.

In making alloys of brass, bronze, or German silver containing manganese, the cupro-manganese must be rapidly melted under charcoal, and added to the alloy, then the whole well mixed and poured as soon as possible. The following are useful proportions :—

	I	II	III	IV
Copper . .	75	65	60	60
Manganese .	25	20	25	20
Zinc . .	...	5	15	...
Tin . .	...	...	...	10
Nickel . .	...	10	...	10

§ 77. **Cupro-ferro-Manganese.**—Mr. Parsons prepares this alloy by mixing a certain proportion of ferro-manganese (an alloy of iron and manganese) with copper, and the product is afterwards made into alloys similar to bronze, brass, and other copper alloys. The ferro-manganese and the copper are melted in separate crucibles, and the ferro-alloy added to the copper. The effect of this combination is similar to that produced by the addition of ferro-manganese to the decarburised iron in the Bessemer converter. The manganese and iron in the metallic state, having a great affinity for oxygen, cleanse the copper of any oxides it may contain, by combining with the oxygen, and rising to the surface, in the form of slag, and thus render the metal dense and homogeneous. A portion of the iron and manganese is utilised in this manner, and the remainder becomes permanently combined with the copper, and plays an important part in improving and modifying the quality of the bronze and brass alloys, afterwards prepared from the copper thus treated. The effect is greatly to increase their strength, hardness, and toughness, the degrees of all of which can be modified at will, according to the quantity of ferro-manganese used and the proportions of iron and manganese it contains. It will be seen from the above that this process of making manganese-bronze is altogether different from that previously described, and that iron is added in addition to manganese.

Another point of great importance which the inventor claims, is the nicety with which both the iron and manganese can be adjusted, and the effect controlled by adding the ferro-manganese in the metallic state to the copper. The amount of manganese required for deoxidising the copper, and for permanent combination with it being well known by experience, it is found that very slight variations in quantity have a perceptible and ascertained effect in modifying the qualities of the alloys produced. The toughness can be increased, and the hardness diminished, or *vice versâ*, at will, precisely as is done in the manufacture of steel by increasing or diminishing the percentage of carbon and manganese. In preparing ferro-manganese for use, Mr. Parsons prefers alloys rich in manganese, containing from 50 to 60 per cent. This is melted with a certain proportion of the best wrought-iron scrap, so as to bring down the manganese to the various proportions required. At the same time any silicon it contains is reduced, and the metal refined. About four qualities of ferro-manganese are made, containing from 10 to 40 per cent of metallic manganese. The lower qualities are used for those copper alloys in which the zinc exceeds the tin, and the higher qualities for those in which tin is used alone, or exceeds the zinc used in the combination; and the amount of ferro-manganese added varies generally from about 2 to 4 per cent.

The Manganese-Bronze and Brass Company have manufactured five different qualities of the above alloy. In the lower qualities the zinc alloyed is considerably in excess of the tin. They are cast into metal moulds and then forged, rolled, or worked hot for rods, plates, sheathing, tubes, wire, etc. They are not adapted for general sand castings. One of the most important applications of the second quality is that of producing articles cast in metal moulds under pressure. Blocks thus cast are said to have all the characteristics of forged steel as regards strength, toughness, and hardness. It is perfectly homogeneous, and while not possessing a fibrous texture derived from rolling or hammering, it is still fibrous in character, and this in not one, but in all directions alike, and when broken shows a beautiful silky fracture. Its tensile strength is from 32 to 35 tons per square inch, and its elastic limit from 16 to 22 tons, with an ultimate elongation of from 12 to 22 per cent. It can be cast on to an object, and will shrink on to it with a force equal to its elastic limit, and when released will show an amount of resilience of about double that of steel. A hoop shrunk on to a solid cylinder of iron gave the following results: it stretched when hot ·03 of its diameter, and, when cold and released, sprang back about ·003 of its diameter.

As regards hardness it is about equal to mild steel. To ascertain its efficiency in this respect, and to compare it with gun-metal, wrought-iron, and steel, the following tests were made, by forcing a knife edged angular die into the flat surface of each of these metals, and No. 2 manganese-bronze cast under pressure. It made a dent of equal length in each of these; the following pressures were recorded:—

Gun-metal	12
Wrought-iron	15
Mild steel	20
,, ,, oil hardened	25
Manganese-bronze as cast	20
,, ,, ,, hardened by pressure	22 to 23

These results point to this material as very suitable for the construction of hydraulic and other cylinders, required to stand great strains, and possibly for ordnance.

No. 3 quality is composed principally of copper and tin in about the same proportions as gun-metal, combined with a large percentage of ferro-manganese. Its chief characteristics are, great transverse strength, toughness, and hardness, the facility with which it can be cast, and the soundness and uniformity of the castings produced. It will stand melting in an ordinary reverberatory furnace without injury to the metal, which is a point of importance in producing large castings. Mr. Parsons states that a bar of this metal, cast in sand in the ordinary way, 1 inch square, placed on supports 12 inches apart, requires upwards of 4200 lbs. to break it, and before breaking it will bend to a right angle, and it will sustain from 1700 to 1800 lbs. before taking a permanent set. This quality of manganese-bronze is used for wheel-gearing, supports and connections of machines, crank-pin brasses, the shells of main and other bearings of marine and other engines, axle-boxes, and other parts of locomotive engines. It is also adapted for statuary and art purposes generally, as well as for large bells.

The most important application of this quality of manganese-bronze from a commercial point of view would appear to be that of steamship screw-propellers. Owing to the great strength of this quality of the metal, and its non-liability to corrosion, propeller blades can be made thinner than even those of steel. Their surfaces are very smooth, and when cast they are said to be theoretically true to form, whereas with steel propellers allowance has to be made for the corrosion which takes place, and their deficiency in toughness, by increasing their thickness, and their form is liable to become distorted in the annealing oven, which they have to pass through after being cast. It has been proved conclusively by the logs of several steamships, that have had their *steel* propellers replaced by *manganese-bronze* blades, that their speed has been increased, and consumption of coal diminished, while the weight, vibration, and strain on the ship and machinery have been considerably reduced. Moreover, these advantages are secured at a considerably less ultimate cost than by the use of steel, taking it upon the average life of a vessel; for although the first cost of a propeller with bronze blades is double that of steel, it is said to be practically indestructible, whereas at the end of about three years steel blades become so corroded that they have to be renewed, which brings up the total cost of steel blades on an average to two or three times that of manganese-bronze.

The soundness and tenacity of No. 3 quality of manganese-bronze was demonstrated by an accident which occurred to the propeller of *Garth Castle* on its launch from the yard of Messrs. John Elder and Co., in 1880. One of the blades came in contact with the jetty, and was bent round without a crack to nearly a right angle, and was afterwards hammered back cold to its original form without detriment. Another example is afforded by the propeller of the North German Lloyd's steamship *Mosel*, which was wrecked. One of the propeller blades, after it was recovered from the wreck, was found to be completely doubled over, thus affording an idea of the toughness of the metal.

The qualities Nos. 4 and 5 of manganese-bronze have no particular claim to strength, but are most effective for the purpose of bearings, slide-valves, slide-blocks, piston-rings, etc.

TESTS OF MANGANESE-BRONZE BY TENSILE STRESS

No.	Description.	Elastic limit in tons per sq. inch.	Breaking stress in tons per sq. inch.	Ultimate elongation per cent.	Remarks.
1	No. 1 rods rolled hot	11·00	29·00	44·6	Mild, annealed for riveting cold.
2		13·17	29·29	33·4	Annealed.
3		23·54	31·60	26·5	As delivered from the rolls.
4		24·32	31·43	23·3	
5		34·40	39·60	11·6	Do. and finished cold.
1	No. 2 plates rolled hot	14·06	28·46	23·2	Pulled across fibre Annealed.
2		14·06	30·13	47·8	,, with fibre
3		14·80	30·78	34·1	,, across fibre
4		16·70	30·10	28·8	,, with fibre
1	No. 2 cast under pressure	18·00	35·00	22·0	Cast in an iron cylinder and pressed while liquid. No. 1 cut from side of ingot and No. 2 from centre.
2		16·23	31·90	12·4	

TESTS OF MANGANESE-BRONZE BY TORSION

No.	Description.	Diameter in inches.	Twisting moments in inch pounds.		Amount of twist in length of one diameter, number of turns.	Remarks.
			Elastic limit.	Breaking stress.		
1	No. 2 cast under pressure	0·622	1170	3360	0·183	Uniform twist.
2		0·624	1200	3372	0·166	,,
3	No. 1 rolled	0·621	1110	2880	0·175	Annealed.
4	Rod	0·621	1980	3242	0·165	Rolled hot and tested as it came from rolls.

No. 3 was removed from machine unbroken. No. 4 was broken, showing a clear shear.

TEST OF A BAR OF MANGANESE-BRONZE NO. 3 BY TRANSVERSE STRESS

(1 *inch square, cast in sand, placed on supports* 12 *inches apart, steady pressure applied in middle of bar.*)

Stress in pounds.	Deflection, stress on, inches.	Per. set, stress off, inches.	Stress in pounds.	Deflection, stress on, inches.	Per. set, stress off, inches.
896	·025	...	2688	·21	·12
1120	·03	...	3136	·44	·34
1344	·04	...	3584	·86	·73
1568	·045	...	4032	1·62	·144
1792	·06	·005 } E limit	4144	1·97	...
1904	·065	·01	4256	Gave way without breaking, and bent to a right angle.	

EXPERIMENTS ON THE TRANSVERSE-STRESS AND TOUGHNESS OF BARS OF MANGANESE-BRONZE AS COMPARED WITH WROUGHT-IRON AND GUN-METAL; MADE BY DROPPING A WEIGHT ON THE MIDDLE OF BAR RESTING ON SUPPORTS AT EACH END.

(*Weight of monkey*, 50 *lbs.; height of fall*, 5 *feet; distance between supports*, 1 *foot; dimensions of bar*, 1 *inch square*, 14 *inches long.*)

No. of Blows.	PERMANENT DEFLECTION IN INCHES, IN THE LENGTH OF 12 INCHES.											
	WROUGHT-IRON.		GUN-METAL.						MANGANESE-BRONZE.			
	Staffordshire rolled.		Cast in sand.						No. 3 cast in sand.		No. 1 forged.	
	No. 1	No. 2	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 3	No. 4	No. 5	No. 6
1	·57	·58	·82	·86	·90	·72	·73	·46	·66	0·60	·59	·60
2	1·10	1·15	1·50	1·58	1·63	1·32	1·42	and broke	1·20	1·15	1·06	1·08
3	1·62	1·71	1·70	2·22	2·35	1·92	1·52		1·70	1·60	1·44	1·50
4	2·13	2·23	and broke	and broke	2·86	1·94	and broke	..	2·23	2·07	1·80	1·89
5	2·65	2·77			and broke	and broke		..	2·67	2·52	2·12	2·26
6	3·19	3·37	..	..			..	..	3·11	2·97	2·45	2·65
7	3·77	3·99	..	..	..	..	..	..	3·58	3·39	2·77	2·99
8	4·39	4·63	..	..	..	..	..	..	4·02	4·04	3·05	3·38
9	not b	roken	..	..	..	..	..	..	not broken	and broke half through	3·33	not broken
10	..	..	..	..	..	..	..	..			not broken	
11	..	..	..	..	..	..	..	..	..			..
12	..	..	..	..	..	..	..	..	..		..	..
13	..	..	..	..	..	..	..	..	..	..	..	..

Gun-metal.—The specimens Nos. 1, 2, and 3 were sent from the locomotive works of one of the railways terminating in London, and tested in the presence of an officer of the department, and fairly represent the qualities of gun-metal ordinarily found in such works, and supplied by brassfounders. Nos. 4 and 5 were cast specially and composed of best selected copper, 16 parts, English tin, 2 parts; No. 6 of copper 16 parts, and tin 2½ parts by weight.

Mr. Parsons states that, in all the different varieties of his manganese-bronze, the elements are combined in atomic proportions; and he claims that by this means the alloys are finer in texture, more homogeneous, stronger, and of a much more stable character than when not so combined; thus in the No. 3 quality the addition of $\frac{1}{4}$ per cent tin, instead of making it harder and stronger, as it ought to do, according to the ordinarily accepted ideas, actually makes it softer, weaker, and the grain coarser; and the same thing occurs if the additional tin is increased $\frac{1}{2}$ or 1 per cent, until the tin arrives at another definite atomic proportion, when an alloy of a different character appears; but it then again becomes close-grained, sound, homogeneous, and stable. As a further proof of the soundness of this theory he states that if the No. 3 quality be passed through an ordinary reverberatory furnace, and exposed to the action of an oxidising flame for a considerable time, no appreciable difference is made in the composition of the alloy. The same remarks, in a great measure, apply to Nos. 1 and 2, and although zinc escapes on remelting, it carries with it an atomic complement of copper, so that the proportions of what remains are not disturbed. This appears to be confirmed by the colour of the condensed fumes, which, instead of being white, as they are when produced from zinc alone, have a beautiful pink colour, which may be attributed to the presence of copper.

Another and perhaps still more palpable proof of the value of combining the metals in their atomic proportions, given by Mr. Parsons, is that, when this is done, the specific gravity of these alloys is perceptibly increased over those not so combined, even though in the latter case the heavier metal be in excess. In No. 1 manganese-bronze, which contains a large amount of zinc, and which, judging by its constituents, ought to be a comparatively light metal, was proved to be equal to that of ordinary gun-metal, composed of copper and tin, and very considerably above the mean weight of the metals composing it, indicating that these metals must have combined in such a manner as each to fit into, and fill up the infinitesimal spaces between the molecules of the other, and if not actually forming what chemists would admit to be a perfect chemical compound, certainly more nearly approaching it than when the metals are mixed together in a haphazard manner.

The stable qualities of manganese-bronze are also due very materially to the action of metallic manganese on copper, by freeing the latter from its oxides, and thus bringing the metals added to it into actual contact, and enabling them to combine in a more perfect manner than would be the case without the presence of a deoxidiser.

ALUMINIUM-BRONZE

§ 78. This is an alloy of copper with aluminium, and is manufactured in different qualities by varying the amount of aluminium, which is generally used in small quantity compared with that of copper. Alloys containing 60 per cent of aluminium and upwards are hard, brittle, and crystalline. With equal quantities of the constituents a soft alloy is obtained, and when the amount of aluminium is less than 30 per cent, the hardness again returns. A very small amount of aluminium in copper reduces its conductivity for electricity considerably. The alloys containing 10 per cent of aluminium downwards are those generally manufactured, and of these the 10 per cent alloy is perhaps the best for all-round properties.

Deville states that 2 to 3 per cent alloys are used by M. Christofle for large castings of works of art. They are harder than aluminium and work well under the "burin" and chisel.

The useful properties of the 10 per cent alloy were first described by M. Debray. It is very hard, can be beaten when cold, but with remarkable perfection when hot, and may be well compared to iron, which it resembles in all these physical properties; it is also very ductile. It behaves as a true alloy, and consequently will not liquate into different combinations. This is proved by the fact that, when in making the alloy, the *pure copper* is in the crucible, and a bar of aluminium is added; the combination takes place with such disengagement of heat that if the crucible is not of good quality it will be fused, for the whole attains a white heat. The colour of the bronze is exactly that of "green gold" (an alloy of gold and silver), and it takes a beautiful polish, being comparable in this regard only to steel. Its chemical properties differ but little from those of most of the alloys of copper. However, in numerous experiments it has been found to resist most chemical agents much better than these, especially sea-water and sulphuretted hydrogen. Its tenacity is equal to steel. According to experiments as to its wear in the form of journal boxes, it is said to wear away less than any other journal metal yet tried. Its malleability is almost perfect, as is seen by the following report of M. Boudaret, a practical engineer: "First, aluminium-bronze is malleable at all temperatures, from bright red to cold; second, it is perfectly malleable at a red heat, breaking less and elongating more than pure copper; third, it is hard to roll in the cold, after several passes it ceases to elongate, and must then be annealed very often, or it will break quickly; fourth, it results from the foregoing, that it is best to roll it at as great a heat as possible below fusion; annealing and tempering render it softer than simple annealing. If after being annealed at a bright red heat, it is let cool in still air to redness and then plunged in cold water, it is ductile and malleable enough in the cold to stand all industrial working."

These facts were announced some time back by the late Dr. Percy. Messrs. Tissier state that, just as copper increases the hardness of aluminium, so aluminium in small proportions increases the hardness of copper; however, aluminium does not injure its malleability, but makes it susceptible of taking a beautiful polish, and according to the proportions, varies its colour from red gold to pale yellow. The alloys alter much less by successive fusions than the alloys of copper with tin and zinc employed for the same purpose. A 10 per cent aluminium alloy is harder than our gold coin, takes a fine polish by burnishing, and has the colour of pale jeweller's gold: it can be forged and worked the same as copper. The 5 per cent aluminium alloy is less hard than the preceding, but, like it, takes a fine polish, and in tint approaches nearly to that of pure gold. Alloys with 5 to 10 per cent of aluminium may have their colour changed at will, either by leaving them in nitric acid, which takes away the copper and leaves the aluminium, or in hydrochloric acid, which takes away the aluminium, leaving the copper. The resistance, hardness, and elasticity, which are communicated to copper by introducing small quantities of aluminium, make these important industrial alloys.

Mierzinski states that "two points are to be attended to in making aluminium bronze. First, *a pure copper must be used.* The best is that electrically deposited, but it generally costs too much. The next best is the Lake Superior brand; the usual commercial copper gives very indifferent results, owing to the antimony, arsenic, tin, zinc, or iron with which it is contaminated. The bronze is deteriorated by being alloyed with zinc or tin. Secondly, the alloy must be remelted two or three times to remove its brittleness."

In all probability the percentage of aluminium increases by remelting. The usual alloys are those of 1, 2, 5, and 10 per cent aluminium. The 5 per cent bronze is golden in colour, polishes well, and casts beautifully; is very malleable cold or hot, and has great strength, especially after hammering. The 7½ per cent bronze is to be recommended as superior to the 5 per cent; it has a peculiar greenish gold colour, which makes it very suitable for ornamental purposes. The 10 per cent bronze has a tenacity of about 100,000 lbs., compressive strength 130,000 lbs., per square inch, and its ductility and toughness are such that it does not even crack when distorted by this load. It is so ductile and malleable, that it can be drawn down under a hammer to the fineness of a cambric needle. It works well, casts well, holds a fine surface under the tool, and when exposed to the weather, it is in every respect one of the best bronzes known. Its high cost has alone prevented its extensive use in the arts. The alloys are very uniform in character. Every 1 per cent of aluminium added to copper causes a considerable increase in ductility, increases its fusibility, and enables it to cast well; 2 per cent gives a mixture used for castings which are to be worked with a chisel. It is softened by sudden cooling from a red heat. Its coefficient of expansion is small at ordinary temperatures. It has great elasticity when made into springs.[1]

The following results were obtained from the Cowles Company's bronzes:—

Grade.	Tensile strength per square inch.	Elongation.
"A" (11 per cent) (special hard)	45 to 50 tons	From nil to 5 per cent
"A 1" (10 per cent)	40 ,, 45 ,,	,, 4 ,, 8 ,,
"A 2" (10 ,,)	34 ,, 38 ,,	,, 8 ,, 17 ,,
"A 3" (10 ,,)	28 ,, 32 ,,	,, 18 ,, 25 ,,
"B" (7½ ,,)	25 ,, 28 ,,	,, 25 ,, 30 ,,
"C 1" (5½ ,,)	21 ,, 25 ,,	,, 30 ,, 35 ,,
"C 2" (5 ,,)	18 ,, 21 ,,	,, 35 ,, 40 ,,
"C 3" (5 ,,)	15 ,, 18 ,,	,, 40 ,, 50 ,,
"D" (2½ ,,)	12 ,, 15 ,,	,, 45 ,, 60 ,,
"E" (1¼ ,,)	9 ,, 12 ,,	,, 20 ,, 35 ,,

The "A special hard," "A 1," and "A 2" grades retain their strength through a great range of temperature. The "B" and "C" grades roll and forge hot, and draw cold. The colour of these latter grades is similar to 18-carat gold, and take and retain a brilliant polish.

Casting of Aluminium-Bronze.—The melting point of aluminium-bronze varies somewhat with the amount of aluminium contained, the higher grades melting at a rather lower temperature than the lower grades. The 10 per cent alloy melts at about the same temperature as gun-metal, or

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[1] Thurston's *Materials for Engineering.*

930° C. It shrinks about twice as much as brass, and due allowance must be made for this in the pattern and mould. As the metal solidifies rapidly it is necessary to pour it quickly and to make the "gates" amply large, so that there will be no "freezing" in the "gates" before the casting is properly fed. To prevent shrinking as much as possible, the metal is allowed to enter the mould at a temperature no higher than will admit of its running freely. Where there is a heavy mass of metal in the shape of an envelope surrounding a core, the contraction upon solidification will cause the metal to split, unless the core is made to yield equally with the contraction. Baked sand moulds are preferable to green sand, except for small castings. Instead of ordinary green sand cores, it is recommended to use resin in coarse sand, and plenty of cinders to make the core yielding. Cores may be made on hay-bands, if large, and as yielding as possible, and the mould must be cut away on the metal setting, to prevent breaking of casting, if the shape requires it.

One of the chief difficulties met with in the casting of aluminium-bronze, is the oxidation in transferring the metal from the crucible or ladle to the mould. If any of the film of oxide which floats on the surface of the metal should get into the casting during the pouring it will appear there like so much dirt, and is apt to cause trouble. The ordinary skim-gate will prevent this in the case of small castings, but with large masses the metal is first poured into a receiver, which is connected with, and is part of, the pouring "gate," but is prevented from entering the mould by means of a plug, which closes up the mouth of the "gate." To illustrate this more clearly, imagine the pouring "gate," shaped like a funnel, into which the metal is first poured. It is prevented from running into the mould by the plug already mentioned. As soon as the dirt has risen to the top the plug is withdrawn, and consequently nothing but the clear metal from the bottom enters the mould. For castings over fifty pounds, the metal is poured from a large ladle through a hole in the bottom. Ample facilities should be made for the escape of gases. Both aluminium and copper volatilise only at very high temperatures, so that alloys of these metals can be remelted without any appreciable change in the strength or quality of the metal. In the case of casting in iron moulds for wire strips, etc., the mould may be blackened with a mixture of plumbago, pipe-clay, and lard oil.

When aluminium-bronze is made by simply mixing the ingredients, it is brittle, and does not acquire its best qualities until after it has been remelted three or four times. It then reaches a maximum, and can afterwards be remelted without sensible change. Thin castings come out very sharp, but if a casting is thin and suddenly thickens, small offshoots must be made at the thick place, into which the metal can run and then soak back into the casting as it cools and shrinks, thus avoiding cavities by shrinkage at the thick part.

§ 79. **Cowles's Electrical Method.**—Aluminium alloys are prepared by the Cowles Electrical Smelting Company in an electrical furnace represented in vertical section in Fig. 29. [1] "It consists of an oblong receptacle, the internal dimensions being 5 feet long, 3 feet 3 inches deep, and 20 inches wide. It is built below the floor line and lined with fire-bricks. Into the ends are built cast-iron tubes, inclined as shown, for convenience in working the electrodes. On the ends of the tubes are covers having bosses upon them, through which pass the electrodes. On the covers are screwed blocks of wood surrounding the bosses. Near the outer ends of the electrode rods are easily removable clamps, each of which holds a nut, through which passes a screw having a T handle at its outer end, whilst its inner end rests against the wooden block. The rotation of this screw moves the electrode inwards or outwards. The top of the brickwork is covered with iron plates, and an iron cover, as shown in Fig. 29, is placed over the mouth of the furnace. In the cover is a hole through which the gases issue as they are driven off by the heat in the furnace. The electrodes consist of carbon rods $2\frac{1}{4}$ inches in diameter, and nine of them are attached to each electrode rod. The attachment, as shown in the figure, consists of metal, which is cast around the ends of the carbons and of the electrode rod, so as to form a conductor, which is in perfect contact with the whole of the parts connected. The metal from which this attachment is cast is selected so as to be suitable for the particular alloy to be treated in the furnace, as, although in comparison with the actual charge, it is not subjected to a very intense heat, the metal of which it is formed is found to exercise a slight influence upon the furnace product.

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[1] Paper by Mr. W. Robey, Cleveland Soc. of Engineers, December 1888.

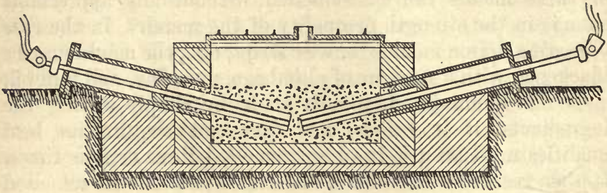

FIG. 29.

"Here, then, we have a covered furnace provided at its ends with two electrodes, which are capable of being easily moved apart. The application of the furnace is as follows: The two electrode rods are connected to the two leads of the dynamo, the cable joined to the positive pole sending the current into the left-hand electrode, whence it travels through the charge, where it meets with the resistance which causes the heat, and passes by way of the right-hand electrode into the cable connected to the negative pole of the dynamo. Resistance is caused by the particles of the carbon which are mixed in the charge. Thus, the current acts independently of the structure of the furnace itself, acting simply on the charge which is in immediate contact with the carbon, by means of which the heat is produced. The heat developed is enormous, and charcoal is found the most convenient form of non-conductor for a protective lining, but the intensity of the heat converts it in a short time into graphite, so that it loses its non-conducting properties. To renew the charcoal frequently is expensive, and the difficulty is overcome by dipping the partially graphitised charcoal into limed-water, the lime being found to render the charcoal again sufficiently non-conducting.

"When charging a cold furnace, some charcoal is put into the bottom, and lightly beaten down till it forms a firm bottom of sufficient thickness. The electrodes are run inwards till their ends nearly meet in the furnace, and the charge is then put into the centre of the furnace, and surrounding the electrode ends. The charge for copper alloy consists of 300 lbs. of materials, about one-fourth being aluminium ore broken up small, a good deal of which is supplied by broken-up slag taken from a former heat, about 4 per cent of carbon, and the balance is granulated copper.

"The ore employed is sometimes *corundum*, also called *sapphire* and *ruby*. The dull crystals are termed *corundum*, and the gray and black varieties *emery*. It is essentially alumina Al_2O_3. At the present time the ore employed in England is *bauxite*, the composition of a sample of which is as follows:—

Silica	2·8
Alumina	57·4
Ferric oxide	25·5
Lime	·2
Titanium oxide	3·1
Water and volatile matter	11·0
	100·0

"This was found to answer equally well, at a fraction of the cost of corundum. The charge while being inserted is prevented from spreading out laterally (in which case some portions of it might be too distant from the electrodes) by two pieces of sheet-iron connected by a distance piece, which are placed one on either side of the electrodes; the charge is put in between them, and the charcoal is then filled in between the sheet-iron and the sides of the furnace, after which the sheet-iron is withdrawn, the top of the charge covered, and the ends of the furnace filled with charcoal to the depth of a few inches above the charge and the electrodes. The iron cover is then luted on with fire-clay. A current of 2000 to 3000 amperes is applied at first, and, as the charge becomes fused, the resistance diminishes. The electrodes are then drawn farther apart, the speed of the engine increased, and a current of 5000 amperes flows through the charge, until the whole of the ore and metal are fused. One operation requires about one hour and three-quarters. It is assumed that the aluminium and copper unite when both are in the gaseous state, and the Company claim that by this means a completeness of union between the constituents of the alloy, and a homogeneity and strength are obtained superior to alloys formed in any other way."

The rich alloys prepared in the electrical furnace just described are used for making aluminium-bronze, brass, and iron, by melting them with copper, tin, zinc, etc., in a crucible in an ordinary furnace, instead of using pure metallic aluminium, and it is found by this means that more perfect and uniform alloys are obtained.

ALUMINIUM-BRASS

§ 80. This alloy is prepared by adding spelter to aluminium-bronze, or by melting together various proportions of ordinary brass and aluminium-bronze. The greater the proportion of the bronze present in admixture, the harder and stronger the brass becomes. Alloys containing copper, zinc, and aluminium between the following limits—

Copper . .	67 to 71
Zinc . . .	31¾ to 25½
Aluminium . .	1¼ to 3½

and combined in different proportions, have a tensile strength varying from 13 to 30 tons per square inch. Alloys with 56 to 57 per cent copper and 40 to 42 per cent zinc approach nearer 31 tons tensile strength. Mr. Robey states that aluminium-brass is composed of $\frac{1}{3}$ of 10 per cent aluminium-bronze, $\frac{1}{3}$ copper, and $\frac{1}{3}$ spelter.

Aluminium-brass is close-grained, homogeneous, and tough, with a useful tensile strength, and great elastic resistance. With regard to transverse stress, a bar of Cowles's No. 2 brass, 1 inch square and 12 inches between supports, showed a breaking load of 72 cwts.; the deflection with 44 cwts. load was ·04 of an inch, and the permanent set ·01. Aluminium-brass forges hot, and, owing to its special casting qualities, low specific gravity, strength, toughness, and rigidity, is very suitable for ships' propellers, rudder frames, pumps, valves, pinions, etc., as well as for hydraulic work. With regard to casting, practically the same rules apply, as those given for aluminium-bronze. Its working qualities, when the amount of aluminium is high, are similar to those of the bronze. The working qualities are also governed largely by the quantity of zinc contained in the brass—the higher the percentage of zinc, the harder the metal, and the shorter the chip which flies from the tool.

Hercules Metal.—This is a cheaper form of aluminium-brass made by the Cowles Company. It casts well, and whilst very hard and strong, works well under the tool. It is malleable when hot, and suitable for all castings where a strong metal is required. Its tensile strength varies from 30 to 40 tons per square inch; with an elongation of 10 to 30 per cent, according to the proportions of the constituents. It contains a proportion of iron as high as $7\frac{1}{2}$ per cent, together with a larger proportion of spelter than in the ordinary brass.

§ 81. The following tests were made by order of the navy department of the United States, and the table shows the favourable results of aluminium bronze and brass as compared with gun-metal.[1]

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[1] Paper by Mr. Dagger, Brit. Assoc. 1889.

TESTS OF ALUMINIUM BRONZE AND BRASS

(UNITED STATES NAVY DEPARTMENT TESTS)

	Mark or No.	Approximate Composition.					Length between reference marks in inches.	Diameter in inches.	Area in square inches.	Tensile strength lbs. per square inch.	Elastic limit lbs. per square inch.	Elongation per cent in 15 inches.	Reduction of area per cent.	Diameter at fracture in inches.	
		Cu.	Al.	Si.	Zn.	Su.									
Aluminium Bronze, or Brass.	1c	91·5	7·75	0·75	..	..	15	1·875	2·7612	60,700	18,000	23·200	30·7	1·56	Chill Castings.
	7c	88·66	10	1·33	..	..	15	1·875	2·7612	66,000	27,000	3·800	7·8	1·80	
	9c	91·5	7·75	0·75	..	..	15	1·875	2·7612	67,600	24,000	13·00	21·62	1·66	
	10c	90	9	1	..	..	15	1·875	2·7612	72,830	33,000	2·40	5·78	1·82	
	11c	63	3·5	0·33	33·33	..	15	1·875	2·7612	82,200	60—73,000	2·33	9·88	1·78	
	11D	63	3·33	·33	33·33	..	15	1·900	2·840	70,400	55,000	0·40	4·33	1·86	
	13c	92	7·5	0·5	..	..	15	1·875	2·7612	59,100	19,000	15·1	23·59	1·64	
	9D	91·5	7·75	0·75	..	..	15	1·900	2·840	53,000	19,000	6·2	15·50	1·75	Dry Sand Castings.
	10D	90	9	1·0	..	..	15	1·890	2·810	69,930	33,000	1·33	3·30	1·86	
	13D	92	7·5	0·5	..	..	15	1·930	2·930	46,550	17,000	7·80	19·19	1·73	
	1	88	..	..	2	10	15	1·875	2·7612	18,000	10,000	2·50	4·70	1·83	Green Sand Castings.
	2	88	..	..	2	10	15	1·875	2·7612	24,590	11,000	8·20	6·80	1·81	
	3	88	..	..	2	10	15	1·875	2·7612	22,500	11,000	5·80	10·89	1·77	
	4	88	..	..	2	10	15	1·880	2·7760	23,000	13,000	4·00	10·36	1·78	
	5	88	..	..	2	10	15	1·880	2·7760	20,570	13,000	2·33	6·30	1·82	
	6	88	..	..	2	10	15	1·880	2·7760	23,750	13,000	3·70	7·30	1·81	

TESTS OF HARDNESS OF LARGE BARS.

(Aluminium Bronze, or Brass.)

Mark.	Hardness of head.	Hardness of stem.
1c	9·39	13·85
7c	14·12	14·26
9c	11·18	13·59
11c	14·69	10·60
10D	17·08	60·07

HARDNESS OF NAVY YARD BRONZE.

Mark.	Hardness of head.	Hardness of stem.
No. 1	3·33	3·33
No. 5	3·67	6·56

The Navy Yard Bronze was furnished by the United States Government, and carefully cast at New York Navy Yard, under inspection of an officer detailed for that purpose.

William H. Harris,
Chief Engineer, U.S.N.

Aluminium alloys containing varying proportions of nickel are made, and are said to be very ductile and to possess a tenacity of from 33 to 44 tons per square inch. Tests made by Kircaldy on similar alloys, manufactured by the "Crown Metal Company," gave results ranging from 39 to 42 tons per square inch. According to Mr. Webster, two alloys are employed by the Company for preparing the bronze, designated as aluminium alloy A and nickel alloy B. The A alloy consists of 15 parts aluminium and 85 parts tin. The B alloy consists of 17 parts nickel, 17 parts copper, and 66 parts tin. The metals are melted in the usual way with the use of a flux, under a cover of common salt and potassium chloride. The two alloys are then melted together with copper. It has been found that the bronze is the harder and better the more it contains of the two alloys, and *vice versâ.* The following is recommended as the best proportion: copper, 88 parts, and 8 parts of each of A and B. The copper is first melted and the alloys added; the mixture is then stirred with a wooden or clay rod (an iron rod must not on any account be used) until the mass is homogeneous, as shown by a test-ingot. A second quality alloy, which is cheaper than the preceding, is composed of 92 parts copper, and 4 parts each of the alloys A and B.

One great drawback to the use of aluminium-bronzes for manufactured articles is the difficulty experienced in soldering and brazing them. The Cowles Electric Smelting Company has issued the following directions:—

§ 82. **Brazing.**—Aluminium-bronze will braze as well as any other metal by using ¼ brass solder (copper 50 per cent, zinc 50 per cent), and ¾ borax.

§ 83. **Soldering.**—To solder aluminium-bronze with soft solder: cleanse well from dirt and grease the parts to be joined. Then place the parts to be soldered in a strong solution of sulphate of copper, and place in the bath a rod of soft iron, touching the parts to be joined. After a while a copper-like surface will be seen on the metal. Remove from bath, rinse quite clean, and brighten the surfaces. These surfaces can then be tinned by using a fluid, consisting of zinc dissolved in hydrochloric acid, in the ordinary way, with soft solder.

Mierzinski says that Hulot uses an alloy of the usual half-and-half lead and tin solder, with 12½, 25, and 50 per cent of zinc amalgam.

CHINESE AND JAPANESE BRONZES

§ 84. The Chinese and Japanese have attained great perfection in making bronzes for art metal-work, of which the following may be taken as typical. The first is called *shakudo*, and contains—

	I	II
Copper	94·61	95·77
Silver	1·55	·08
Gold	3·73	4·15
Lead	·11	...

The above have been used for very large works of art, such as colossal statues. Professor Roberts-Austen states that the quantity of gold is very variable, some specimens which he analysed containing only 1·5 per cent gold. The other alloy is termed *shibu-ichi*, of which there are many varieties. The precious metals are employed to produce definite results.

	I	II
Copper	67·31	51·05
Silver	32·17	48·83
Gold	traces	·12
Iron	·52	...

The gold enables the metal to receive a beautiful rich purple "patina" or coating when treated with certain pickling solutions, while *shibu-ichi* possesses a silver-gray tint, which becomes very beautiful under ordinary atmospheric influences. There are three pickling solutions generally in use. They are made up respectively in the following proportions, and are used boiling :—

	I	II	III
Verdigris	438 grains	87 grains	220 grains
Sulphate of copper	292 ,,	437 ,,	540 ,,
Nitre	...	87 ,,	...
Common salt	...	146 ,,	...
Sulphur	...	233 ,,	...
Water	1 gallon	...	1 gallon
Vinegar	...	1 gallon	5 fluid drachms

[1] "That most widely employed is No. I. When boiled in No. III solution pure copper will turn a brownish red, and *shaku-do*, which contains gold, becomes purple. Copper containing a small quantity of antimony gives a very different shade to that resulting from the pickling of pure copper. But the copper produced in Japan is often the result of smelting complex ores, and the methods of purification are not so perfectly understood as in the West. The result is that the so-called 'antimony' of the Japanese art metal-workers, which is present in the variety of copper called *kuromi*, is a complex mixture containing tin, cobalt, and other metals, so that the operator has a varied series of materials at command with which to secure any particular shade. Each particular tint is the result of very small quantities of metallic impurity.

"Another art material termed *mokumè*, which signifies wood grain, is very rare. It may be imitated by soldering thin sheets of different metals or alloys together, layer upon layer,[1] as shown in Fig. 30. Then drill conical holes of varying depth, A, in the mass, or devices in trench-like cuts of V section, B, and hammer the mass until the holes disappear; the holes will thus be replaced by banded circles, and the trenches by banded lines. Prominences as at C may be produced by bumping up the soldered layers from the back with blunt tools. These prominences are filed down until the sheet is flat; the branded alloys then appear on the surface in complicated sections, and a remarkable effect is produced, especially when the colours of the alloys are developed by suitable pickles.

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[1] Roberts-Austen, *Jour. Soc. of Arts*, 26th October 1888.

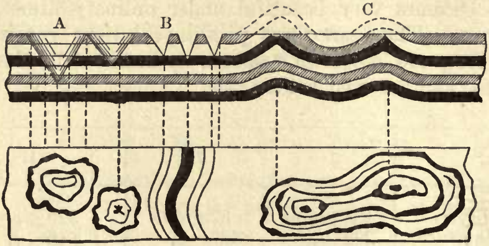

FIG. 30.

"Oriental art metal-workers often blend metals and alloys of different colours, by pouring them together at a temperature near the solidifying point of the more infusible of the metals and alloys to be associated. In this way, by pouring the comparatively fusible, gray silver-copper alloy on to fused copper, which is just on the point of 'setting,' the metals unite, but do not thoroughly mix, and a mottled alloy is produced."

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[1] The solder used by Professor Roberts-Austen contained—

Silver	55·5
Zinc	26·0
Copper	18·5
	100·0

Some Chinese and Japanese bronzes have an unusually deep bronze colour, and in some cases possess a very beautiful dead-black "patina." The following analyses by H. Morin show the composition :—

	I	II	III	IV	V
Tin . .	4·36	2·64	3·27	3·23	5·22
Copper . .	82·72	82·90	81·30	83·09	72·09
Lead . .	9·90	10·46	11·05	11·50	20·31
Iron . .	·55	·64	·67	·22	1·73
Zinc . .	1·86	2·74	3·71	·50	·65
Arsenic . .	...	·25	...	·25	...

The peculiar black colour was proved to belong to the substance of the bronze and not to a superficial coating of sulphide. It increases in intensity with the proportion of lead present. The presence of zinc rather impairs the colour.

[1] "In imitation of the above bronzes the following alloys were made by Morin :—

	I	II
Tin . . .	5·5	5
Copper . . .	72·5	83
Lead . . .	20·0	10
Iron . . .	1·5	...
Zinc . . .	·5	2

No. I gave an alloy exceedingly difficult to work, and without giving any superior results as regards colour, furnished castings which were extremely brittle. No. II, on the contrary, gave an alloy exactly resembling Chinese bronze. Its fracture and polish were identical, and when heated in a muffle, it quickly assumed the peculiar dead-black appearance so greatly admired in Chinese specimens. Hitherto it has been found difficult, if not impossible, to obtain this depth of colour with modern art bronzes, since the surface scales off when heated under similar conditions."

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[1] *Compt. rend.* tom. lxxviii. p. 811.

Christophle and Bouillet confirm the results of Morin's analyses, but point out that the presence of lead is by no means essential to the production of a fine black "patina." By peculiar oxidation processes they profess to have succeeded in producing brown, orange-yellow, red, and black patina on pure copper. They are said to consist of the production of cuprous-oxide in two molecular states and of copper sulphide.

Two Japanese bronzes, analysed by Kalischer, and having the colour of brass (*Ding. pol. J.* tom. ccxv. p. 93), contained—

	I	II
Tin . . .	4·48	4·36
Copper . . .	76·64	76·53
Lead . . .	11·88	12·20
Zinc . . .	6·53	6·58
Iron . . .	·47	·33

Japanese bronzes analysed by Maumené (*Compt. rend.* tom. lxxx. p. 1009) gave the following results:—

	I	II	III	IV
Copper . .	86·46	80·91	88·70	92·07
Tin . . .	1·94	7·55	2·58	1·04
Antimony .	1·61	·44	·10	...
Lead . .	5·68	5·33	3·54	...
Zinc . .	3·26	3·08	3·71	2·65
Iron . .	·69	1·43	1·07	3·64
Silica . .	·10	·16	·09	·04
Sulphur . .	...	·31	...	...
Waste . .	·26	·79	·21	·56

These alloys showed a hard, granular texture, with small cavities on the interior, and sound on the exterior. In the presence of much antimony their colour becomes sensibly violet, and red with the presence of much iron. The specimens were from 5 to 12 millimetres thick. The alloys were probably not made by melting the metals together, but prepared directly from the ores.

WHITE METALS FOR BEARINGS

§ 85. The metals entering into the composition of the various alloys employed for the above purpose are: copper, tin, antimony, lead, and zinc; but seldom more than three of these constituents are used in any one alloy. In machinery running at high speed, or with great pressure, the bearing surfaces are subject to considerable friction, and in many cases the object of the engineer is rather to reduce this friction to the lowest degree, than to provide a bearing which will withstand great pressure without wearing away. A common practice at the present time is to make the foundation of brass or bronze, and line the bearing surface with a renewable lining of comparatively soft white metal. One great advantage of white metal is its low melting point, so that a worn-out bearing can be readily melted out and replaced by a new one. The white metal is generally melted in an ordinary ladle, and when the journal or mandril is wiped dry and chalked, the molten metal is poured in. Care should be exercised not to raise the metal to too high a temperature, as it not only causes the constituent metals to oxidise unequally, but volatile metals escape, and thus the composition is considerably altered. No dross should be allowed to pass into the bearing along with the metal. The journal should also be warm, so as not to chill the metal too suddenly at the wearing surface. White metal bearings are indispensable for certain purposes; as, for instance, where the shaft resting in the bearing does not run smoothly. If the bearing be made of hard metal, considerable friction is set up and a battle will take place between the axle and the bearing, the softer of the two being worn away, causing the axle to swerve considerably. By the use of a soft metal "liner" the axle is not worn, and adapts itself to the condition of the bearing, and runs with much less friction than in the previous case, and, as stated before, the lining is easily replaced when worn away too much. This tendency of white metal to reduce friction has given rise to the term "anti-friction" metal as a name for such alloys. The points of great importance in a bearing are: (1) that it should not cut the journal, (2) should be durable, (3) not become heated by friction, (4) sufficiently soft to adapt itself to the bearing surface, and (5) the metal should be capable of being readily melted and cast. Red metal bearings are distinguished by great hardness and power of resistance, and used where the speed is high and the pressure great.

§ 86. **Babbit's Anti-friction Metal.**—This was once largely used, but is now replaced in many cases by other alloys. Mr. Babbit recommended to melt together 4 lbs. copper, 8 lbs. antimony, and 24 lbs. tin. This he called hardening. For every pound of the above, he added 2 lbs. more tin. Since its introduction many different mixtures have been sold under the same name, some of the tin being replaced by zinc and lead. One receipt gives 2 lbs. antimony, 2 lbs. tin, and 20 lbs. lead. The bearing to be lined with Babbit's metal is recommended to be washed with alcohol, and powdered over with sal-ammoniac; and those surfaces which are not to be coated, are to be covered with a clay-wash. It is then to be warmed sufficiently to volatilise a portion of the sal-ammoniac, and then tinned.

§ 87. A white metal alloy for bearings has recently been introduced, under the fanciful title of "magnolia metal," and appears to have found considerable patronage for marine and railway work. Professor R. H. Smith of Mason's College, Birmingham, has submitted this metal to a variety of tests, and states "that it is much superior to either Babbit's metal or gun-metal. It produces less friction, keeps the bearing temperature lower, requires less lubrication, and possesses greater durability. This characteristic of durability is a most important one. Within the wide limits covered by my tests, it would be true to say that the longer the magnolia metal is used, and the more severe the duty imposed upon it, the better becomes its condition. The elevation of bearing temperature above that of the surrounding air is extremely low. The general conclusion I have arrived at from my experiments is, that magnolia metal is a very excellent metal for bearings; that its specially good qualities appear more particularly when it is subjected to intense pressures, such as could not be borne by other metals without firing or melting, and that under very trying circumstances magnolia metal may be trusted to remain cool—that is, at a temperature that does not interfere with good working."

An analysis of this metal, made by Mr. Dean in the author's laboratory, gave approximately—

Lead	78
Antimony . . .	21
Iron	1
	100

§ 88. The following table shows the composition of various white alloys for bearings :—

	Tin.	Copper.	Antimony.	Lead.	Zinc.	Iron.
Kingston's metal with 6 per cent of mercury added	88	6	...	...	...	...
Fenton's metal for axle-boxes of locomotives and waggons	14·5	5·5	...	...	80	...
Stephenson's alloy . .	31	19	...	...	19	31
For Propeller boxes . .	14	57	...	...	29	...
Dewrance's metal for locomotives	33·3	22·2	44·4	...	...	...
Hoyle's alloy for pivot bearings	46	...	12	42	...	...
Jacoby's alloy . . .	85	5	10	...	...	...
For Propeller bush . .	26	5	...	...	69	...
Very hard bearing . .	12	4	82	...	2	...
Anti-friction metal . .	14	6	...	...	80	...
For general bearings . .	81	5	...	14	...	...
,, ,, . .	81	5	14	...	...	...
,, ,, . .	...	10	10	80	...	...
,, ,, . .	...	12	...	88	...	...
Bearings for light work .	85	5	10	...	...	...
,, ,, .	73	9	18	...	...	...
,, ,, .	76	7	17	...	...	...
,, heavy work .	90	2	8	...	...	...
,, ,, .	87	6	7	...	...	...
,, common work .	2	8	2	...	88	...
Soft alloy for pillow-blocks	...	...	15	85	...	...
Vaucher's alloy for lining journals	18	...	2·5	4·5	75	...

MELTING AND CASTING OF BRONZE

§ 89. Bronze is prepared in crucibles, and in reverberatory furnaces, according to the quantity required for casting. The general rule is to melt the copper first, then add the scrap-metal, and when these have been thoroughly melted together, to add the tin, or tin and zinc, as the case may be, previously heated as much as possible without melting. The addition of the tin cools the copper, and as it is advisable to get the whole charge melted and mixed as quickly as possible, in order to prevent loss by oxidation and volatilisation, the fire should be kept very brisk while the alloying is taking place.

Bronze contracts on solidifying, as with other copper alloys, but the amount of contraction depends on the composition and on the temperature at which it is cast, varying from $\frac{1}{130}$ to $\frac{1}{77}$ of its bulk.

The difficulties attending the casting of bronze are much the same as those already discussed with regard to brass. The tin shows a greater tendency than copper to unite with oxygen, so that in remelting bronze the alloy becomes a little richer in copper, and therefore a slight excess of tin should be added in the first place, to supply the subsequent loss. The metals should be excluded as much as possible from the atmosphere during melting, by covering the surface with charcoal or anthracite powder, or oxides will be formed, which will be dissolved by the molten alloy, and impair its strength and toughness. Moreover, bronze has the property of absorbing air and other gases when in the molten state, and emitting them as the surface solidifies. If the castings are thick, or the cast metal rapidly chilled, the absorbed gases cannot escape from the interior, and therefore produce numerous small hollow spaces or pin-holes. Gases are removed more perfectly from molten metal by mechanical agitation, such as vigorous stirring with a suitable rod, and if the rod be of wood, or carbonaceous material, some of the dissolved oxides are decomposed, the oxygen combining with the carbon and escaping as a gas. The other impurities also more readily rise to the surface through the agitation, and form dross. It is probably for a similar reason that phosphorus, manganese, and other reducing agents, when added in small quantity, are so efficacious in producing sound castings.

The loss of metal in melting, as well as the quality of the product, is influenced by the construction and arrangement of the furnace. In a reverberatory-furnace a neutral or reducing atmosphere should be maintained, so as to avoid unnecessary oxidation, but the chief point is to get the metals melted and mixed as rapidly as possible; for, if bronze is kept fused for a considerable time, a white alloy rich in tin separates from the main mass, as previously mentioned.

The crucible furnace employed for making bronze is similar to the brass-making furnace, Figs. 7 to 12.

CHAPTER V

GERMAN SILVER

§ 90. The alloys, largely manufactured under this name, consist essentially of nickel, copper, and zinc. Different names are used to signify the same substance, such as: *Nickel-Silver*, *Argentan*, *Packfong*, *White-Copper*, *Weisskupfer*, *Neu-Silver*, and *Maillechort*. Besides these, different manufacturers employ fanciful names to denote alloys containing different proportions of the constituent metals, which they consider best suited to produce a given result, a good white colour being a great desideratum. Thus: *Nevada Silver*, *Virginia Silver*, *Potosi Silver*, *Silveroid*, *Silverite*, *Electrum*, *Afénide*, *Agiroide*, etc., are simply German silver; but in some cases a little cobalt is present as well as nickel, and some makers add a small quantity of iron or manganese. 1 to 3 per cent of lead is sometimes added for cast work.

The properties which make German silver so valuable are:—its white colour, lustre, hardness, tenacity, toughness, malleability, ductility, and power of resisting certain chemical influences. When carefully prepared it works well under the stamp, and between the rolls, but it is advisable that the metals used in alloying should be as pure as possible, since small quantities of certain impurities, such as arsenic, seriously injure its working qualities. Cobalt frequently accompanies nickel in its ores, and becomes reduced at the same time as that metal, and alloys readily with it; but as the chemical and physical properties of both metals are closely allied to each other, cobalt does not exert an injurious influence.

Iron has a beneficial effect on German silver for some purposes. It makes the colour whiter, increases the tenacity and elasticity, but makes it harder. In some experiments made by the author, 1 to 2 per cent of iron was found to have no deteriorating effect, except with regard to hardness, and the colour of an alloy containing 12 per cent of nickel was equal to one containing 16 per cent, in which no iron was present, the same quantity of zinc being used in each case. The metal rolled remarkably well. In the better qualities of German silver used for rolling and spinning, iron was found to be injurious, and for these purposes the purer the alloy the better it works. All commercial varieties of German silver contain iron, especially when scrap-metal is used in connection with new metal for the melting charge, the iron being probably obtained from files and other tools used in the fabrication of the various articles. Packfong, the original nickel alloy introduced from China, contains as much as 3 per cent of iron. Gersdorff states that iron is difficult to alloy with the other constituents, and when that metal is added to fused German silver it does not combine with it, and forms upon the surface of the fused mass a layer, consisting of copper, nickel, and iron. He states that the iron must be previously fused with a portion of the copper, under a layer of charcoal-powder in a blast-furnace, and the alloy formed may then be used to alloy with the nickel, zinc, and the remainder of the copper required. This is quite unnecessary, as proved by the author's experiments, in which copper nickel and the best iron wire were strongly heated together in a covered crucible, and zinc added to the molten contents, then vigorously stirred. The metals were perfectly alloyed together, and no separation of iron could be detected when the ingot was rolled into a thin sheet and highly polished.

The effect of tin when alloyed with German silver to the extent of from 2 to 4 per cent was found much more injurious than that of iron, the strips being brittle when rolled, and the metal of a decidedly yellow cast when polished. From his experiments the author concludes that there is no advantage in adding tin to German silver, as it impairs the colour, hardens the metal, and makes it brittle. Moreover, tin is an expensive metal, and better effects can be obtained by the use of iron and zinc. An alloy, patented more than fifty years ago, had the following composition:—

Copper	55
Zinc	17
Nickel	23
Iron	3
Tin	2
	100

Silver in certain proportions does not impair the malleability of German silver, but no particular advantage is gained by its use. M. Ruolz many years ago manufactured a series of alloys for jewellery having the following composition:—

Silver	20 to 30
Nickel	25 to 30
Copper	35 to 50

By varying the proportions the alloys may be made to resemble silver very closely; but the nickel and copper must be of good quality, or the alloys will be hard, brittle, and difficult to work. It is stated that French jewellers still use these and similar alloys. An old alloy, termed American nickel silver, contains—

Iron	1 part.	Manganese	4 parts.
Cobalt	1 ,,	Nickel	24 ,,
Silver	2 ,,	Zinc	36 ,,
Tin	2 ,,	Copper	96 ,,

Another alloy, having the same advantage of being complex, which is its chief merit, was introduced by Mr. Toucas, and consists of—

Copper	35·8 parts.	Lead	7·1 parts.
Nickel	28·7 ,,	Zinc	7·1 ,,
Antimony	7·1 ,,	Iron	7·1 ,,
Tin	7·1 ,,		

According to the inventor, it has nearly the colour of silver, may be worked like it, and laminated by the ordinary processes; it is resisting, susceptible of a fine polish, with the lustre of platinum, and may be silvered perfectly well. He recommends it for objects which are to be spun, hammered, or chased; but for cast and adjusted pieces he prefers to increase the proportion of zinc, in order to increase the fluidity of the metal.

Modern proportions for German silver alloys vary considerably, each manufacturer having a preference for his own particular mixture for any given quality. For metal which is to be rolled, pressed, or stamped, the alloy must be tough and malleable; and as whiteness in colour is an important consideration, it follows that the metals nickel and zinc must be present in considerable quantity in order to overcome the red colour of the copper. For cast work, which only requires to be filed and turned, malleability is not of first importance, it being sufficient if the metal has the requisite tenacity and toughness, and also sufficient liquidity when melted and adaptability to ordinary moulding purposes. Another item, which cannot be ignored, is that of cost, and as nickel is an expensive metal, it is to the advantage of the manufacturer to employ as much zinc as is consistent with the properties enumerated above.

Founders whose specialty is the manufacture of German silver have agreed that the best alloy for beauty, lustre, and working properties consists of the following proportions:—

Copper	46
Nickel	34
Zinc	20

It is also the most costly among similar alloys, on account of the large proportion of nickel present.

§ 91. The alloys most largely employed for spoons, forks, and other table and ornamental goods contain from 6 to 22 per cent nickel; the lower qualities being little better than brass, and only used for the very commonest goods, and the higher qualities approximating to pure nickel in whiteness. In order to determine the best proportions to employ for alloys containing 8, 10, 12, 16, and 20 per cent respectively of nickel the following experiments were made by the author. In all cases the copper and nickel were melted together under a layer of charcoal, and a little borax added as a flux. The zinc was added when the former were well fused; and the whole was well stirred with a wooden rod before pouring the metal into the iron mould. Ordinary commercial metals were employed.

Alloys containing 8 per cent Nickel

	I	II	III	IV
Copper	58	60	62	64
Nickel	8	8	8	8
Zinc	34	32	30	28

No. I was the whitest, but the weakest, and rolled the worst of the series. No. II was whiter than Nos. III or IV, and was the toughest of the four; an experimental ingot about $\frac{1}{4}$ inch thick was bent double in a vice without cracking. It rolled well, but was not so malleable as Nos. III and IV. Nos. III and IV rolled equally well, but No. III was a shade the whiter.

Alloys containing about 12 per cent Nickel

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Copper	57·5	57·5	57	55	58	57	56	55	56	55	54	53
Nickel	12·5	12·5	12	12	12·5	12·5	12·5	12·5	12·5	12·5	12·5	12·5
Zinc	30	28	31	31	29·5	30·5	31·5	32·5	29·5	30·5	31·5	32·5
Iron	..	2	..	2	..	..	..	..	..	..	..	..
Tin	..	..	..	..	..	..	..	..	2	2	2	2

With regard to malleability, as proved by rolling, the following order was observed, the numbers given being in the order of their capability of being rolled: Nos. IV, III, VI, II, $\underbrace{\text{I, V,}}$ VII, VIII, IX, X, XI, XII. No. IV not only rolled the best, without cracking on the edges, but was also the whitest in colour. All the ingots were numbered, and passed in succession through the rolls, the ingots being of the same thickness at the commencement. The condition of each was noticed after each squeeze of the rolls, and the thickness accurately measured. They were all likewise annealed together under the same conditions. The first six in order—that is, Nos. IV, III, VI, II, I, V—rolled well, Nos. I and V being equal in this respect. Nos. VII and VIII rolled moderately well; and Nos. IX to XII rolled badly, the strips splitting down the middle long before they were reduced to the requisite thinness. For the above rolling tests the author is indebted to Mr. Wilcox of Messrs. Kemp and Co., Birmingham. The above results may be summarised as follows:—That 30 to 31 per cent of zinc, with less than double the amount of copper, gives the best results with respect to malleability and whiteness; 32 per cent of zinc makes the alloy more brittle and requires more frequent annealing during the rolling process; 1 to 2 per cent of iron may be present without seriously impairing the malleability, the alloys being whiter and harder; tin is very injurious, and imparts a yellowish tint to the alloy, even 2 per cent making the alloys unworkable.

Alloys containing 16 per cent Nickel

	I	II	III	IV	V
Copper . .	62	60	58	56	54
Nickel . .	16	16	16	16	16
Zinc . .	22	24	26	28	30

No. V was the whitest and behaved itself irreproachably during rolling. Nos. III and IV were about equal in malleability, rolled better than No. II, and were whiter in colour. No. I was the worst of the series, both as regards colour and malleability. Any higher proportion of zinc, with 16 per cent of nickel, would probably be injurious. It is here noticeable that the best results were obtained with 30 per cent zinc, as in the 12 per cent nickel alloys, but with a less percentage of copper.

ALLOYS CONTAINING 20 PER CENT NICKEL

	I	II	III	IV	V
Copper . .	60	58	56	54	50
Nickel . .	20	20	20	20	20
Zinc . .	20	22	24	26	30

No. I rolled badly, but the casting was not sound, through being poured too hot, which somewhat impaired its malleability. No. III rolled well, although slightly cracked on the edges. No. IV rolled remarkably well with a clear feather edge. No. V was about equal to No. III, but whiter in colour. From these experiments it appears that 30 per cent zinc with 20 per cent nickel is rather too much; probably 28 per cent would combine the advantages of whiteness and malleability in the highest degree.

§ 92. The following analyses by the author of different articles made of German silver, by different makers, may be instructive :—

	I	II	III
Copper . .	66·0	59·2	55·0
Nickel . .	8·2	16·0	20·7
Zinc . .	25·3	23·8	23·3
Iron . .	·5	1·0	1·0

The above were three different qualities made by the same firm. No. I had been boiled white in a tinning solution, and the tin was polished off before analysis.

	I	II	III	IV	V	VI
Copper . . .	61·8	47·10	55·40	53·1	55·75	53·3
Zinc . . .	29·6	41·95	31·38	29·98	26·15	24·4
Nickel . . .	8·3	10·95	11·64	16·25	18·10	21·0
Iron . . .	·3	...	1·58	·67	trace	1·3

The above were various qualities manufactured by another firm. No. VI was found to work very badly, probably due to iron, which is more injurious as the percentage of nickel is greater.

The following table gives the composition by analysis of German silver from various sources :—

Authority.	Percentage Composition.					
	Copper.	Nickel.	Cobalt.	Zinc.	Iron.	Lead.
1. Fyle	40·4	31·6	...	25·4	2·6	...
2. Fricke	50	31·2	...	18·8	...	...
3. Guettier	53·3	26·6	...	20·1	...	...
4. ,,	51·6	26	...	22·4	...	...
5. Krupp	51·6	25·8	...	22·6	...	...
6. ,,	48·5	24·3	...	24·3	...	2·9
7. Hiorns	56·98	24·3	...	18·72	...	...
8. Guettier	59	22·2	...	18·5	...	0·3
9. ,,	55·2	21·4	...	23·4	...	...
10. Hiorns	59·1	20·2	...	20·4	0·3	...
11. ,,	56·5	20·3	...	23·2	...	...
12. Henry	67	19·3	...	13·6	...	...
13. Louyet	63·34	19·13	...	17·41	...	...
14. D'Arcet	50	18·75	...	31·25	...	...
15. Hiorns	58	18·5	...	23·5	...	...
16. Smith	60	18·8	3·4	17·8	...	...
17. Krupp	58·3	19·4	...	19·4	...	2·9
18. Hiorns	53·1	16·25	...	29·98	·67	...
19. ,,	55·62	15·72	...	28·66	...	...
20. ,,	56·84	15·62	...	27·24	·30	...
21. Louyet	62·4	15·05	...	22·15	trace	...
22. Krupp	57·8	14·3	...	27·1	...	·8
23. Hiorns	58·72	13·85	...	26·43	1·00	...
24. ,,	57·0	13·4	...	27·60	2·00	...
25. Elsner	57·4	13·0	...	26·6	3·00	...
26. Hiorns	55·4	11·64	...	31·38	1·58	...
27. Louyet	62·63	10·85	...	26·52	...	...
28. Rochet	59·1	9·7	...	31·2	...	...
29. Hiorns	66	8·2	...	25·3	·50	...
30. Krupp	63	6	...	31	...	...

The alloys in the preceding table containing lead are used for casting only, that metal making the alloy more fusible.

MANUFACTURE OF GERMAN SILVER

§ 93. The manufacture of German silver was formerly conducted in two distinct ways, known respectively as the *German* and *English* methods.

German Process.—In the German method the zinc and nickel to be used for a certain quantity of copper are divided into three equal portions. On the bottom of a graphite crucible, capable of holding 22 lbs. of the alloy, is placed a layer of copper, and upon this a layer of zinc and nickel; upon this another layer of copper is placed, and so on until all the copper is in the crucible. One-third each of zinc and nickel is retained for future addition. The contents of the crucible are then covered with charcoal powder, and the metals melted in an ordinary casting-furnace. When the contents are supposed to be liquefied, an iron rod is inserted, and if the whole is thoroughly fused, it is then vigorously stirred. The remaining zinc and nickel are then added in portions at a time, and the whole well stirred after each addition, a brisk fire being maintained to prevent chilling of the alloy by the freshly added metals. After the introduction of the last portion, an additional piece of zinc is thrown into the crucible to compensate for loss of zinc by volatilisation. If the alloy is intended for rolling, it is recommended to keep the finished alloy liquid for some time longer before casting, keeping the surface well covered with charcoal in the meantime.

English Process.—The English differs from the German method chiefly in the manner in which the metals are melted together, no portion of the zinc and nickel being retained, but the entire quantity of metals consisting of 8¼ lbs. copper, ½ lb. zinc, and 2 to 3 lbs. nickel is melted at one time. The mixed metals are placed in a red-hot crucible and quickly covered with a thick layer of coal-dust. The furnace is urged to its highest pitch, so as to fuse the metals as quickly as possible. After ascertaining by an iron rod that the mass is liquefied, a previously prepared alloy, of 1 part by weight of zinc and ½ part by weight of copper, is added, the quantity for the above charge varying between 1¾ and 2 lbs. When this alloy is melted, and the entire contents of the crucible forms a homogeneous whole, 2 lbs. of zinc are finally added. The mass, being kept covered with coal-dust, is then heated as strongly as possible, and when thinly fluid, a sample is taken to test its qualities.

The metals during melting always absorb oxygen, which is liable to produce blow-holes when the alloy is cast. The nature of the alloy may be ascertained by taking a small quantity as a test, and if this exhibits unsoundness, some makers push a fire-clay pipe to the bottom of the crucible, and drop some pitch through it to the bottom of the metal, and then remove the tube. The pitch is decomposed, giving rise to reducing gases which combine with the oxygen in the metal, and by vigorous stirring before pouring, are removed.

It need hardly be stated that the distinctive methods of working, just described as the German and English methods, are not generally carried out at the present time, a modification being found more rapid, economical, and attended with equally good results.

The separate metals entering into the composition of German silver are not generally used in the free state, but are previously made into binary alloys. Thus, nickel is alloyed with copper by some manufacturers in the proportion of 2 parts by weight of copper to 1 part of nickel, while others use equal weights of these metals. Zinc is used in the form of brass, common mixtures consisting of equal weights of copper and zinc, and 2 parts zinc to 1 of copper.

The crystalline nature of German silver when cast in iron moulds renders the metal somewhat difficult of mechanical manipulation, especially when the amount of nickel present is high, but this may be overcome by careful annealing at a moderate temperature, and by judicious hammering. Of course there are certain proportions which give better results than others, as shown by the author's experiments on the subject already enumerated. The crystalline structure gradually disappears as the plates are reduced by rolling, with occasional annealing as the process proceeds, and when the strips have been rolled sufficiently thin for ordinary stamping purposes, the cause of brittleness has been practically eliminated, so that the alloy can be worked into any desired form.

It has been found in practice that certain varieties of German silver become more homogeneous by remelting, and can be worked with greater facility, but this is unnecessary if suitable proportions are selected at the commencement, and copper-nickel alloys with copper-zinc alloys used for melting together to form the desired alloy, instead of using the separate metals. It must also be remembered that each time German silver is remelted in a crucible in the ordinary way, a certain amount of oxide is formed, and a greater portion of the zinc than the copper or nickel is volatilised, so that the relative amounts of the constituents are altered. In the case of remelting it is necessary to add a portion of metallic zinc to compensate for the loss, and it is advisable to add this zinc after the fusion of the alloy has been effected. There is reason to believe that the zinc thus added assists in purifying the metal, by uniting with the absorbed oxygen. Whether this is so or not, the author has proved that such an addition is beneficial in many cases, if not in all.

Great care is required in casting the alloy to avoid chilling of the metal, and as a high temperature is requisite to keep the metal sufficiently liquid for pouring into the moulds, the casting shop is kept closed and all spaces which ordinarily admit cold air are stopped up. All the precautions with regard to blacking and heating of the moulds, etc., as described when speaking of brass strip-casting and moulding, apply also to German silver. But as German silver is more easily chilled than brass, it may be necessary, after one mould is filled, to re-heat the remaining portion of metal in the crucible before pouring it into a second mould.

The moulds used for German silver strip-casting are of the same shape as those described for brass-strips, but differ in size. The running sizes of plate-ingots are 16 to 18 inches long, 4, 4½, and 5 inches wide, and 1 to 1¼ inches thick. The wire-ingots are about 4 feet 6 inches to 5 feet long, 3¼ inches wide, and 1¼ inches thick.

GERMAN SILVER SOLDERS

§ 94. Hard solders, employed for joining the parts of German silver articles together, are generally made of the same metals as those which compose the alloy to be soldered, but in such proportions as to have a lower melting point. In general, the soldering is more perfect the nearer the fusing point of the solder approaches that of the metal of which the article is composed, but the greater is the care required to avoid melting it. In some cases silver solder is used for German silver articles; and German silver solder is also used for soldering articles of iron and steel, on account of its high melting point and great tenacity.

German silver solder is known by different names, such as "argentan solder," "arguzoid," etc. It is rendered moderately fusible by the addition of a large proportion of zinc to the copper and nickel. The mode of manufacture is similar to that already described for brass solder, and the proportions of the ingredients will depend upon the composition of the alloy which it is required to solder. For the higher alloys, *i.e.* those rich in nickel, a more refractory solder is advisable than with the cheaper and more fusible alloys.

In making argentan solder the copper and nickel should be melted first, and the zinc added in the free state, or in the form of brass, containing much zinc. The mixture is then cast in thin plates, which are broken into pieces while hot, and crushed to powder in an iron mortar. The facility with which it can be pulverised will depend upon the proportion of zinc. If it is too brittle it indicates too much zinc, and even if somewhat malleable, too much zinc may be present; in either case the defect may be remedied by adding the fresh metal required and remelting. Excess of zinc may be removed by remelting, when some of that metal will burn off, but this is of course wasteful and expensive. The right composition can always be determined by taking a small quantity and testing it before pouring the main portion. The colour is grayish-white, with a strong lustre.

In order to test the best proportions for soldering articles containing 16 to 22 per cent of nickel, the author obtained a sample of the solder used by a large manufacturer for the above alloys, which, on analysis, gave the following proportions:—

Copper	47·10
Nickel	10·95
Zinc	41·95
	100

The following trial samples were then prepared:—

	I	II	III
Copper	45	38	35
Nickel	10	12	8
Zinc	45	50	57
	100	100	100

The three samples were pulverised whilst hot, and tested by a workman accustomed to use the solder of which the analysis is given above. He considered No. II the best for soldering, but preferred the one he had been accustomed to use. No. III was pronounced porous, from which it was inferred that 57 per cent zinc was too much.

CHAPTER VI

ALLOYS OF TIN

§ 95. **Tin and Zinc.**—Alloys of these metals can be readily produced by fusion, forming combinations that are generally harder and less malleable than tin, softer than zinc, and more or less crystalline in structure. The colour of the fractured surface depends upon the nature of the mould and the temperature of the alloy at the time of casting. The same observations also apply to the shrinkage upon solidification. Tin-zinc alloys are chiefly employed for casting ornamental objects, and patterns.

The following investigation into the character of tin-zinc alloys was made by Guettier[1] :—

"1. *Tin* 30, *Zinc* 70.—Texture of a dull-white colour; an average shrinkage; breaks easily; on fracture shows larger and brighter facets than zinc; the metal is denser at the bottom of the mould; dry to the file; breaks under the chipping chisel; slightly sonorous; and shows an appearance of crystallisation at the surface, with a slight bluish-yellow colour.

"2. *Tin* 25, *Zinc* 75.—Texture of a white colour, inclining to blue; slight shrinkage of the bar; bright fracture with large bluish facets like those of zinc; the tin seems to be in larger proportion at the bottom of the button, the same as in No. 1; the surface is covered with a kind of skin, rather wrinkled than crystalline, and with variegated colours,—light blue, violet, and golden yellow.

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[1] Guettier, *Guide Pratique des Alliages*, 1865.

"3. *Tin* 50, *Zinc* 50.—Texture, pallid white; surface of the ingot is very smooth, granular, and lamellar, without the appearance of shrinkage; the edges are somewhat round, and do not show plainly the iridescent colours; the fracture is bright and finely granular, upon a tin-white ground; and clogs the file a little; the alloy is well mixed, tough, and malleable, without being soft.

"4. *Tin* 70, *Zinc* 30.—Texture white; and somewhat shining; exhibits no settling; feebly sonorous; surface granular, and dead white with slightly yellow spots; difficult to break; bears hammering well; easily worked with the chisel, which takes off long chips; it clogs the file; the fracture, like that of tin, is without brightness and crystallisation; when polished it is less bright than tin; the alloy is more complete and uniform in texture than the preceding ones.

"5. *Tin* 75, *Zinc* 25.—Texture tin-white, but without brightness; exhibits no settling; surface granular and studded with bright particles; the upper surface has a tint changing from yellow to reddish-blue; clogs the file more than No. 4; very malleable, although resisting the hammer and chisel more than No. 4; bends without the crackling sound of tin.

"6. *Tin* 10, *Zinc* 90.—The bar shows at the fracture the characteristics of a zinc bar; clogs the file more than zinc; the fracture is not of so dull a gray; the bottom of the button is soft and easily receives the impression of a punch; like No. 2, tin appears to settle, and the metal at the bottom is softer than pure tin.

"7. *Tin* 90, *Zinc* 10.—The bar presents the jagged fracture of tin, and the runner could only be separated by cutting it; the alloy clogs the file less than pure tin; the button settles sensibly in the middle, although the edges are sharp; the alloy is very malleable, although not very soft under the hammer.

"8. *Tin* 1, *Zinc* 99.—The fracture is like that of zinc, but the facets are less; lustre is slightly brighter after filing; middle of the bar had settled; the button also settles in the middle, and the lower part was soft like No. 6, although not so thick, on account of the small proportion of tin in the alloy; the soft portions are bluish like lead, and are easily streaked by the nail.

"9. *Tin* 99, *Zinc* 1.—The fracture is slightly granular, and not so dull and jagged as that of tin; when polished is not so bright as tin; there is more shrinkage on the ingot than on the button, and the surface of the latter presents dark iridescent colours.

"**General Observations.**—The alloys where the proportion of zinc is the greatest, present in their fracture a crystallisation whose facets shine like graphite. Very small proportions of tin added to zinc cause this crystallisation. In similar circumstances the exterior of the castings is covered with a yellowish-white *moiré.*

"In thick castings, where zinc predominates, there is a tendency for the metals to separate at the bottom of the mould; and, what is remarkable, this tendency grows greater as the proportion of tin becomes smaller, which is exemplified by the separation being more sensible in No. 8 than in No. 6. We may add as a singular anomaly that the tin which has passed through the zinc, and has become precipitated, loses its distinctive qualities and acquires the softness and bluish dull colour of lead.

"The colour of the alloy of zinc and tin, whether simply cast, or after being filed, becomes brighter in a direct ratio with the proportion of tin contained in it.

"The alloys already rich in tin become granular when the proportion of zinc is increased. The alloy No. 3—tin 50, zinc 50—has the fracture of iron, but its colour is duller.

"The alloy No. 9—tin 99, zinc 1—has a fracture presenting no longer the jagged appearance of tin, and is dull-gray and finely granular in structure.

"The specific gravity of the alloys of tin and zinc is in proportion to the mean specific gravity of the two metals, therefore the alloys where tin predominates are more dense.

"The waste is greater where zinc is in excess; the tin having been put into the crucible after the fusion of the zinc, we infer that most of the waste comes from the zinc.

"The addition of 1 per cent of tin to zinc is sufficient to impart to the latter metal a greater resistance without diminishing its hardness. 1 per cent of zinc added to tin impairs the flexibility of the latter, and, what is remarkable, prevents its peculiar crackling noise. These two alloys when the combination is intimate, present no other sensible changes.

"The alloy of tin 50, zinc 50, is the best as regards stiffness and economy. More zinc would produce an alloy not so well mixed, more crystalline, and brittle; more tin would give a metal too soft and clogging the file. However, for thin and resisting castings an alloy of tin 70, zinc 30, is well adapted. The alloys kept between these figures and the proportion of half and half are very resisting and tenacious. Their malleability increases with the proportion of tin.

"The alloy of zinc 1, tin 99, without impairing the malleability of the latter metal, increases its hardness and tenacity for castings.

"The alloys where the maximum of zinc is employed are useful in foundries only for thick pieces; they are then very economical. Up to the portions of tin 30, zinc 70, they remain nearly as brittle as zinc itself. The proportion of tin 25, zinc 75, produces an alloy not so flexible as and less brittle than zinc, which could be adopted for foundry patterns.

"The alloys Nos. 6 and 8 appear to us more brittle than zinc. In those experiments tin passing through the molten mass into the mould had become precipitated to the bottom. We may infer from this that a quantity of tin, sensibly less than 1 per cent, is sufficient to change the nature of zinc.

"In the proportions of tin 40, zinc 60, the alloy possesses but little malleability."

An alloy of 11 parts tin to 1 part zinc, beaten out into leaf, forms spurious silver-leaf.

According to Rudberg $ZnSn_6$ (1 part zinc to $10\frac{3}{4}$ parts tin) solidifies completely at 204° C., but all the other alloys separate on cooling from a state of fusion into two portions, the one consisting of $ZnSn_6$, not solidifying till cooled to 204° C., while the remainder, consisting of an alloy containing a larger proportion of one or the other metal, solidifies at a higher temperature: thus:—

	$Sn_{12}Zn$	Sn_6Zn	Sn_4Zn	Sn_3Zn	Sn_2Zn	$SnZn$
Variable point .	210	...	230	250	280	320
Fixed point . .	204	204	204	204	204	204

A metal, now largely employed for buttons, is prepared by rolling a thin sheet of tin on each side of a thick sheet of zinc. The metals become firmly welded together, and the pressed work has the advantage of a coating of tin.

§ 96. **Tin and Lead.**—These metals are easily melted, and unite together in all proportions, forming a series of valuable alloys. Lead leaves a dark mark when drawn across paper, and when only a limited quantity of tin is alloyed with it, this property is still retained; but if a certain limit be exceeded, the alloy no longer has the property of producing the dark mark; hence it is possible to roughly estimate the quantity of the lead present by this test, taken in conjunction with the behaviour of the metal under the hammer, file, and chisel. Tin 90 parts, and lead 10 parts, does not streak paper. Tin 75, lead 25, gives a very faint mark. Between these limits no mark can be observed when the alloys are drawn across paper. All lead-tin alloys containing less than 75 per cent of tin have the power of marking paper.

Alloys of lead and tin shrink, or settle less on cooling than either of the metals taken singly; they are not so fluid when melted, and the castings have not the same sharpness.

The effect of lead on tin is to increase its malleability and ductility, but to diminish its tenacity and toughness. In the alloy, tin 90, lead 10, tin preserves the crackling noise, but in a less degree than in pure tin. On the contrary, 1 per cent of zinc in tin is sufficient to destroy the crackling noise when the metal is bent.

The following table contains the results of Kuffer's experiments with respect to the specific gravities and melting points of lead-tin alloys. The author has added the percentage compositions.

Composition of the alloys.			Specific gravity.		Difference.	Melting point.
Formula.	Per cent.		Calculated.	Found.		
	Pb.	Sn.				
Pb . .	100	...	...	11·3803	...	335° C.
Sn . .	0	100	...	7·2911	...	230° ,,
SnPb * .	63·7	36·3	9·4366	9·4263	0·0103	241° ,,
$SnPb_2$.	77·82	22·18	10·0936	10·0782	0·0154	...
$SnPb_3$.	84·04	15·96	10·4122	10·3868	0·0254	239° ,,
$SnPb_4$.	87·42	12·58	10·6002	10·5551	0·0431	...
Sn_2Pb .	46·73	53·27	8·7518	8·7454	0·0064	196° ,,
Sn_3Pb .	36·90	63·10	8·3983	8·2914	0·0069	186° ,,
Sn_4Pb .	30·49	69·51	8·1516	8·1730	0·0096	189° ,,
Sn_5Pb .	25·85	74·15	8·0372	8·0279	0·0093	194° ,,
Sn_6Pb .	17·04	82·96	7·9526	7·9210	0·0116	...

* Sn = 118. Pb = 207.

"Alloys of lead and tin are distinguished by the facility with which they ignite and burn. The alloy of 4 or 5 parts lead and 1 part tin burns like charcoal at a red heat, the combustion continuing like that of an inferior peat, with the formation of cauliflower excrescences. The action appears to be due to the affinity which exists between the two oxides."[1]

§ 97. *Pewter* is essentially an alloy of lead and tin, to which small quantities of other metals are sometimes added.

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[1] Watt's *Dict. of Chem.* p. 534.

Common pewter consists of tin 80 parts and lead 20 parts. Holtzapfel states that some pewters are made nearly as common as that of equal parts of the metals; when cast they are black, shining, and soft; when turned they are dark and bluish. Other pewters only contain $\frac{1}{5}$ or $\frac{1}{6}$ of lead; these when cast are white, without gloss, and hard. Such are pronounced very good metals, and but little darker than tin. The French legislature sanctions the employment of 18 per cent lead with 82 per cent tin, as quite harmless in vessels for wine and vinegar. The finest pewter, called *tin* and *temper*, consists chiefly of tin, with only a little lead and copper, which make it hard and somewhat sonorous, but the metal becomes brown in colour when the copper exceeds a certain quantity. The copper with twice its weight of tin is melted, and from $\frac{1}{2}$ lb. to 7 lbs. of this alloy termed *temper* are added to a block of tin, weighing from 360 to 390 lbs. Zinc in small quantity is added to the molten alloy, and the mixture well stirred. The operator considers that the zinc removes impurities, bringing them to the surface as dross, and also that the burning of the zinc during casting lessens the oxidation of the pewter.

Unalloyed tin is now being largely used in place of pewter, and it is not only whiter in colour, but for domestic purposes it is certainly safer, on account of the poisonous nature of lead compounds, although, as before stated, lead when thoroughly alloyed with tin may be present to the extent of 18 per cent without injury. An alloy of 3 parts lead and 5 parts tin is used for tinning certain articles of copper. Alloys of lead and tin have a bright lustrous appearance, and are used for the manufacture of stage jewellery. The so-called *Fahlum brilliants* are made of an alloy of 39·6 parts lead and 60·4 parts tin. The molten alloy is poured into moulds faceted in the same manner as diamonds. Toys, such as tin-soldiers, and many other articles are made of alloys of lead and tin.

For tempering various articles of steel, where it is important to have a definite and uniform temperature, Messrs. Parkes and Martin have proposed the following alloys :—

Alloy.		Temperature of melting.		Articles.
Lead.	Tin.	C	F	
14	8	213·4	415·4	Lancets.
15	8	221	429·8	Other surgical instruments.
16	8	228	442·4	Razors.
17	8	240	464	Penknives, cold chisels.
28	8	257	494·6	Shears, gardeners' tools.
36	8	262	503·6	Axes, planes, small scissors.
60	8	275	527	Table knives, large scissors.
96	8	284	543·2	Swords, watch-springs.
100	8	289	552·2	Strong springs, augers, saws, etc.

The same authorities have determined the melting points of lead-tin alloys; their results are embodied in the following table:—

Composition.		Melting point.		Composition.		Melting point.	
Tin.	Lead.	F	C	Tin.	Lead.	F	C
50	50	372	189	12·5	87·5	527	275
60	40	336	169	11·8	88·2	530	277
66·7	33·3	340	170	11·1	88·9	532	278
71·4	28·6	348	175·5	10·5	89·5	535	279·5
75	25	354·2	179	10	90	538	281
77·8	22·2	362	183	9·5	90·5	540	282
80	20	367	186	9	91	542	283
81·8	18·2	372	189	8·7	91·3	544	284·5
83·3	16·7	378	192	8·3	91·7	546	285·5
84·6	15·4	380	193	8	92	548	286·5
85·7	14·3	382	194·4	7·7	92·3	550	287·7
40	60	412	211	7·4	92·6	551	288·3
33·3	66·7	442	228	7·1	92·9	552	289
28·6	71·4	470	243	6·7	93·3	554	290
25	75	482	250	6·4	93·6	555	290·5
22·9	77·1	490	254·4	6·3	93·7	556	291
20	80	498	259	6·2	93·8	557	291·7
18·2	81·8	505	263	6	94	557	291·7
16·7	83·3	512	267	5·9	94·1	557	291·7
15·4	84·6	517	269·5	5·7	94·3	557	291·7
14·3	85·7	519	270·5	5·5	94·5	557	291·7
13·3	86·7	523	273	5·4	94·6	558	292

According to Tilden,[1] the most fusible alloy of lead and tin consists of very nearly 2 parts tin to 1 part lead, or 3·3 atoms of tin to 1 atom of lead. The melting points of this and other alloys are graphically represented by the following curve, Fig. 31:—

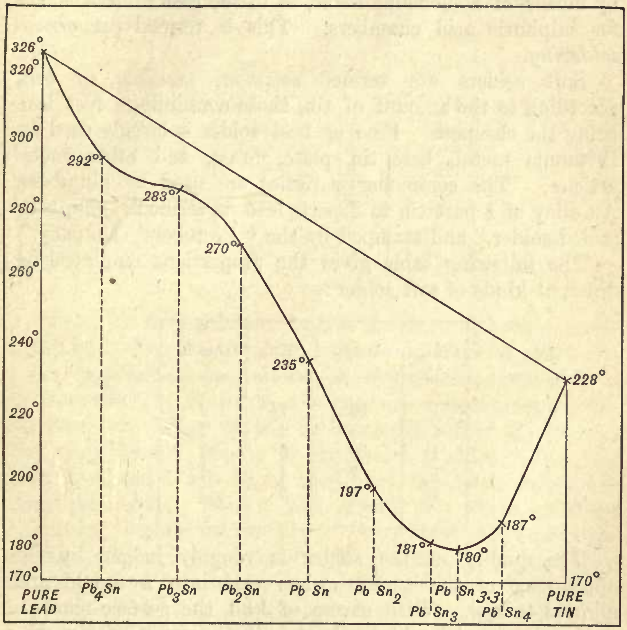

Fig. 31.

Soft Solders

§ 98. Soft solders usually consist of lead and tin in various proportions, and to a certain extent the fusibility of the alloy increases with the content of tin; but this does not apply when the tin exceeds 67 per cent. When a more fusible solder is required, the metal bismuth is added in addition, and sometimes cadmium. Metallic tin is sometimes used alone, as in soldering fine utensils of tin plate. Lead is also soldered to lead by simply melting the edges by means of a blowpipe flame, as in the case of lead sheets for sulphuric acid chambers. This is termed *autogenous soldering.*

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[1] *Chem. Philosophy*, p. 15.

Soft solders are termed *common*, *medium*, or *best*, according to the amount of tin, those containing most lead being the cheapest. Fine or best solder is largely used for Britannia metal, best tin-plate, brass, and other metal articles. The commoner varieties are used by plumbers. An alloy of 1 part tin to 2 parts lead is termed "plumbers' sealed solder," and stamped by the "Plumbers' Company."

The following table gives the proportions employed for different kinds of soft solder:—

Tin.	Lead.	Tin.	Lead.
1	10	1½	1
1	5	2	1
1	3	3	1
1	2	4	1
1	1	5	1

The quality of the solder is roughly judged by the appearance of the surface when cast into a mould and allowed to cool. With excess of lead, the surface shows a uniformly grayish-white colour. With excess of tin, the surface is bright with dull grayish-white spots; in fact, the appearance approximates to that of lead or tin according to the amount of lead or tin present.

§ 99. **Alloys of Tin, Lead, and Zinc.**—The presence of lead imparts more body and resistance to the alloys of tin and zinc than when tin and zinc alone are used, but the triple alloys clog the file as much as the latter. The fractures are more decided than tin-zinc alloys. When the three metals are present in about equal proportions, the alloys are malleable, although not very ductile, and may be economically employed in some cases.

[1] Various alloys are given in the following table :—

	Tin.	Zinc.	Lead.
1	76	12	12
2	12	76	12
3	12	12	76
4	34	33	33
5	10	45	45
6	45	45	10
7	45	10	45

No. 2 is as hard and brittle as zinc, although more resisting. No. 3 resembles hard lead, leaves a mark on paper, appears to be uniform in composition, and has a leaden colour. Both these alloys are better adapted for castings than either of the three metals taken separately. Nos. 1, 3, and 7 appear to withstand friction very well. Nos. 2, 4, and 5 will do for work requiring more resistance than pure zinc. No. 6 will answer for small castings requiring a certain malleability. It is serviceable for ornaments, and will bear engraving and chasing. For these uses Nos. 2, 4, and 5 would be too brittle ; and Nos. 1, 2, and 7 too soft and yielding. All these alloys of tin, zinc, and lead have little lustre when polished, and become readily tarnished by exposure to air. Some of them may be used as type metal. Most of them may be easily rolled.

It is preferable to melt the zinc at the lowest possible temperature, to add the tin, and then the lead. The metals should be covered with charcoal, or with resin, and a little borax added, in order to prevent oxidation. For white alloys, the best proportions are within the following limits:—

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[1] Guettier, *Guide Pratique des Alliages*, 1865.

Tin	67	73
Zinc	16½	13½
Lead	16½	13½

The proportion of zinc is increased if toughness and hardness are desired. More tin increases the malleability, whiteness, and lustre. But the proportion of lead should not much exceed the amount indicated above.

§ 100. **Alloys of Tin and Antimony.**—These metals when united together form the base of what is termed Britannia metal, many varieties of which consist of tin hardened by antimony. Such alloys are as white as tin, but harder and less malleable. The brittleness increases as the proportion of antimony is greater. Guettier states that the specific gravity of tin-antimony alloys is below that which would be calculated from the specific gravity of each metal taken singly. This indicates that expansion takes place by the union of these metals. An alloy of 80 parts tin and 20 of antimony is sufficiently malleable to be hammered and rolled in the cold. It is by keeping near these proportions that the best alloys of tin and antimony, for making pots and engravers' plates, are obtained. A white metal desert-spoon analysed by the author was found to contain—

Tin	79
Antimony	20
Copper	·6
Iron	·4
	100·0

The following table will show the proportions of different tin-antimony alloys:—

	Tin.	Antimony.
Britannia metal . .	90·7	9·2
,, ,, . .	94	6
Algiers metal . . .	90	10
,, ,, . . .	75	25
For seats of stopcocks .	86	14
For plugs of stopcocks .	80	20
Very hard alloy, and forms the extreme limit of ordinary antimony-tin alloys	67	33
Metal for bearings . .	79	21

According to Chaudet, 10 parts tin to 1 part antimony form a perfectly ductile alloy.

Alloys of tin and antimony are made by fusing the two metals together. Also they may be made by reducing sulphide of antimony in contact with tin.

§ 101. **Britannia Metal.**—Reference has just been made to some alloys called by this name, consisting of tin and antimony, but more generally other metals in small quantities are added to the mixture, such as copper, zinc, lead, bismuth, etc. Britannia metal has a white colour, with a bluish tint; it takes a high polish, is hard, malleable, and ductile in proportion to the amount of tin and copper present. The latter metal, however, must always be limited in quantity, as it tends to impart a yellowish tint, and diminish the fusibility, for which reasons the quantity of copper used is always very small compared with the tin and antimony. Good alloys show a fine-grained jagged fracture. If the alloy exhibits a crystalline fracture, it either contains too much antimony, or requires to be remelted in order to promote more intimate union of the constituents. Iron and zinc appear to be very objectionable, as they considerably increase the hardness and brittleness. If much zinc is used to make a cheap alloy, the antimony must be in much smaller amount than is usual with better alloys. Lead is advantageous in cast work, making the alloy more fusible, but it impairs the colour and lustre, and the alloy tarnishes more readily in air than in alloys in which lead is absent. Arsenic, even in small quantity, induces brittleness, and should be avoided as much as possible. Alloys containing metals other than tin and antimony are less brilliant in lustre than when these two metals alone are employed. The following table shows the composition of a few varieties of Britannia metal :—

Britannia metal.	Tin.	Antimony.	Copper.	Zinc.	Bismuth.	Lead.	Other metals.
English . . .	94	5	1	...	...	...	...
,, . . .	90	6	2	...	2	...	...
,, . . .	90	7	3	...	...	...	...
,, . . .	89·3	7	1·8	...	...	1·8	...
,, . . .	85·47	9·66	1·81	3·06	...	...	...
,, . . .	85	5	3·5	1·5	5	...	...
,, . . .	80	10	9	...	...	1	...
,, . . .	75	8·5	...	...	8	8·5	...
,, (sheet) . .	90·6	7·8	1·5	...	...	...	...
,, (cast) . .	90·6	9·2	0·2	...	...	...	...
Queen's metal . .	50½ to 75½	16½ to 8½	...	...	16½ to 8	16½ to 8	...
,, ,, . .	88·5	7·1	3·5	0·9	...	...	...
,, ,, . .	88·5	7	3·5	...	1	...	...
English Tutania . .	25	25	...	...	25	...	Brass 25
German ,, . .	7	92	1	...	...	...	...
Engestrum ,, . .	7	62	31	...	...	...	...
Biddery metal (India) .	...	...	3·5	93·4	...	3·1	...
,, ,, ,, .	1·4	...	11·4	84·3	...	2·9	...
Ashberry metal . .	80	14	2	1	...	...	Nickel 3
,, ,, . .	79	15	3	2	...	...	1
Minofor ,, . .	68·5	18·2	3·3	10	...	...	...
German . . .	72	24	4	...	...	...	...
,, . . .	84	9	2	5	...	...	...
,, . . .	20	64	10	6	...	...	...

In addition to the alloys given in the preceding table many other combinations are employed to produce white alloys having certain desired properties, but the use of complicated alloys is much to be deprecated, for, as a rule, the stability is much greater the simpler the mixture; and although a useful alloy may be produced by careful manipulation, the proportions are disturbed when the scrap is remelted, or mixed with new metal and remelted. The author would therefore recommend a triple mixture of tin, antimony, and copper in preference to a more complex one, especially for wrought work.

The preparation of Britannia metal is based on the idea of rendering tin harder, tougher, more sonorous, and more easily polished. It furnishes castings as fine and sharp as those made with the most fluid alloys of tin and lead, copper and zinc, etc. It acquires a finer polish than alloys of tin and lead, because the latter is too soft to bear the action of emery and other polishing materials. A little brass is sometimes added, and bismuth increases the fusibility. The following proportions will serve as a guide:—

1 part brass (70 copper, 30 zinc)
1 ,, tin
1 part bismuth
1 ,, antimony

These are melted together; then the alloy so formed is fused with 15 to 20 per cent more tin, according to the judgment of the operator. A very complex alloy, termed by the inventor *English metal*, consists of—

Tin . .	87 parts	Bismuth .	½ part
Copper . .	2 ,,	Antimony .	6 ,,
Brass . .	1 ,,	Tungsten .	1½ ,,
Nickel . .	2 ,,		

Britannia metal is best prepared by melting the copper first, then adding the antimony with a portion of the tin, and finally adding the remainder of the tin. The mixture requires to be vigorously stirred in order to thoroughly incorporate the contents. If the alloy upon fracture shows a non-homogeneous structure, it requires to be rapidly remelted under a layer of charcoal, to prevent oxidation. Certain alloys are very elastic, and well fitted for making wire. In this respect they possess nearly the same amount of tenacity as pure tin. With good mixtures the alloys may be easily stamped and rolled, although they have a tendency to crack on the edges.

Dr. Karmarsch, who has carefully studied the properties of Britannia metal, states that the specific gravity is diminished by rolling, the metal having a greater density in the cast state than after rolling. He explains this by assuming that the particles under the pressure of the rolls have a tendency to become separated, their softness and tenacity not being great enough to allow of a regular and uniform compression. This is not an isolated fact. M. le Brun has found a lower specific gravity for certain alloys of copper and zinc which have been laminated or hammered.

To obtain clear and fine castings of Britannia metal it is best to use brass moulds. Before casting, the moulds must be heated, and coated on the interior with a mixture of lamp-black and oil of turpentine, or lamp-black alone, in order to prevent the metal adhering to the mould. The moulds can be so coated by smoking them with the flame of a lamp, filled with oil of turpentine. Instead of lamp-black some manufacturers use reddle or red-chalk, mixed to a uniform mass with water.

Many articles cannot be cast in one piece with ordinary moulds; but the parts require to be cast separately, and afterwards soldered together. [1] "To cast an article such as a coffee-pot in one piece requires great skill and judgment. The separate parts of the mould having been blacked, are put together, and the whole heated nearly to the temperature of the melting point of Britannia metal. The metal is then poured in until the mould seems entirely filled. After waiting until it may be supposed that a sufficiently thick layer of metal is solidified, the mould is quickly turned over to allow the still liquid portion to run out. The inside of articles obtained by this method is sometimes roughly crystalline. This is due to the metal beginning to crystallise, and the corners and edges of the small crystals being exposed by pouring out the liquid portion of the metal. The interior of the articles can be smoothed by a burnisher while they are still in the mould."

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[1] Brannt, *Metallic Alloys*, p. 280.

FUSIBLE ALLOYS

This name is given to a series of alloys which melt at comparatively low temperatures, and consist chiefly of tin, lead, and bismuth. Before considering these triple alloys a brief account will be given of the combinations of tin and bismuth alone.

§ 102. **Tin and Bismuth.**—Both these metals possess low melting points, and they readily combine in all proportions when fused together. A very small proportion of bismuth imparts to tin more hardness, sonorousness, lustre, and fusibility. On that account a little bismuth is added to tin to increase its hardness. However, bismuth being easily oxidised, and often containing arsenic, it is not advisable to use much of that metal in alloy with tin for culinary vessels, etc. The alloys of tin and bismuth are more fusible than either of the metals taken separately.

[1] "An alloy of 354 parts (3 atoms) of tin and 420 parts (2 atoms) bismuth, when cooled from a state of fusion, exhibits but one solidifying point; inasmuch as it first cools regularly down to 143°, and then remains at that temperature for some time, till the latent heat, set free in the solidification of the alloy, has had time to escape. But all other alloys of these metals likewise exhibit a higher solidifying point, the excess of one or the other metal, or rather, another definite alloy containing an excess of one of the two metals solidifying first, and afterwards, at 143° C., the hitherto fluid alloy containing Sn_3Bi_2. The higher solidifying point, or point of separation, is 190° for Sn_4Bi, 160 for Sn_2Bi, 170 for Sn_2Bi_3, and 190° for $SnBi_2$." The

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[1] *Rudberg. Pogg. Ann.* tom. xviii. p. 240.

percentage composition of the above alloys with their melting points is shown in the following table:—

	Tin.	Bismuth.	Solidifying point.
Sn_3Bi_2 . .	45·73	54·27	143° C.
Sn_4Bi . .	69·21	30·79	190° ,,
Sn_2Bi . .	52·91	47·09	160° ,,
Sn_3Bi_3 . .	27·25	72·75	170° ,,
$SnBi_2$ . .	21·93	78·07	190° ,,

Chaudet states that an alloy of 40 parts tin to 1 part bismuth is perfectly ductile; the addition of 1 part lead diminishes its extensibility. An alloy of 25 parts tin to 1 part bismuth is slightly ductile. According to Lewis an alloy of 8 parts tin to 1 part bismuth melts at 199° C. An alloy of 3 parts tin to 1 part bismuth is pulverisable, of a dull-gray fracture, and has a specific gravity of 7·776. An alloy of 2 parts tin to 1 part bismuth melts at 166° C. An alloy of 1 part tin to 1 part bismuth is perfectly brittle, pulverisable, with a fine-grained fracture, and has a specific gravity of 8·345. It melts at 138° C. according to Lewis, and expands considerably in solidifying. Döbereiner found that the alloy Sn_3Bi_2 melts between 131° and 137° C.

§ 103. **Alloys of Tin, Bismuth, and Lead.**—Alloys containing these three metals are more fusible than those containing only two of them. They are useful for ascertaining a given temperature; for making easily melted plastic metals, in order to obtain casts of delicate objects which may be damaged by too high a temperature; for making very fusible soft solders; and lastly, as a matter of precaution, for such apparatus as is liable to be instantaneously destroyed by a sudden and excessive increase of temperature. In this connection may be mentioned the fusible safety plugs of boilers, which were formerly very extensively used.

The fusible alloys are based on the property of certain metals to become more fusible when combined than they were when taken singly. Bismuth, tin, and lead especially follow this rule. When cadmium is added in addition, the alloys are still more fusible. It is difficult to obtain these alloys in a perfectly homogeneous state, as they have a tendency to become decomposed while solidifying from a state of fusion, the lead separating somewhat to the bottom of the mass. The most fusible alloy of lead, bismuth, and tin consists of equal parts of lead and tin, and twice the quantity of bismuth; it melts at 94° C. According to Erman, it dilates in an anomalous manner when heated. It expands regularly from 32° to 95° C. and then contracts gradually to 131°; at which point it occupies a less bulk than it did at 32°; it then expands till it reaches 174°, and from that point its expansion is uniform. On account of this property of expanding as it cools, while still in the soft state, it is much used for taking impressions from dies, as even the faintest lines are reproduced with the minutest accuracy. A peculiarity of this alloy is that it will become hot again, enough to burn the fingers, after it has been cooled in cold water. The cause of this phenomenon is attributed to the effect of latent heat. During the solidification and crystallisation of the inside portions of the alloy, the latent heat of these parts is immediately transmitted to the cooled surface.

Mr. Darcet has studied the properties of the following alloys:—

1. Bismuth 70, lead 20, tin 40.—Softens at 100° C. without melting, and may be kneaded between the protected fingers.
2. Bismuth 80, lead 20, tin 60.—Softens at 100° C. and is easily oxidised. There is, however, too much tin.
3. Bismuth 80, lead 20, tin 40.
4. Bismuth 160, lead 40, tin 70.
5. Bismuth 90, lead 20, tin 40.

These three alloys become more or less soft at 100° C. No. 4 becomes softer than Nos. 3 or 5.

6. Bismuth 160, lead 50, tin 70.—Becomes nearly fluid at 100° C.

7. Bismuth 80, lead 30, tin 40.—Becomes liquid at 100° C., but not very fluid.

8. Bismuth 80, lead 40, tin 40.—Becomes very liquid at 100° C.

9. Bismuth 80, lead 70, tin 10.—Becomes soft at 100° C., but does not melt.

10. Bismuth 160, lead 150, tin 10.—Neither liquid nor soft at 100° C.

These alloys are generally harsh; nevertheless they may be cut. Their fracture is a dead blackish-gray. They are rapidly tarnished in the air, and more so in boiling water, in which they become covered with a wrinkled pellicle, which falls as a black powder. Messrs. Parkes and Martin have also studied the properties of fusible alloys of tin, bismuth, and lead, and recommend these alloys as baths for tempering tools. The article to be tempered is placed on the alloy, which is then heated until it melts. The article is then of the required temper, and is quickly cooled in water. Alloys of lead and bismuth have also been tried, but they are too easily oxidised, and have a great tendency to separate on cooling. Alloys of bismuth and tin succeed better. Those best known are—

Bismuth.	Tin.	Melting point.
50	50	160° C.
33	67	166° ,,
20	80	200° ,,

Parkes and Martin's results are given in the following table:—

Bismuth.	Lead.	Tin.	Degrees F.	Bismuth.	Lead.	Tin.	Degrees F.
8	5	3	202	8	16	24	316
8	6	3	208	8	18	24	312
8	8	3	226	8	20	24	310
8	8	4	236	8	22	24	308
8	8	6	243	8	24	24	310
8	8	8	254	8	26	24	320
8	10	8	266	8	28	24	330
8	12	8	270	8	30	24	342
8	16	8	300	8	32	24	352
8	16	10	304	8	32	28	332
8	16	12	290	8	32	30	328
8	16	14	290	8	32	32	320
8	16	16	292	8	32	34	318
8	16	18	298	8	32	36	320
8	16	20	304	8	32	38	322
8	16	22	312	8	32	40	324

Newton's fusible alloy is the same as No. 1 of the above table.

Rose's alloy consists of—

Bismuth . . .	2
Tin	1
Lead	1

Onions' alloy consists of—

Bismuth . . .	5
Tin	2
Lead	3

and melts at 197° F.

For delicate castings the following proportions are recommended:—

	I	II	III	IV
Bismuth . . .	6	5	2	8
Tin . . .	3	2	1	3
Lead . . .	13	3	1	5

These alloys expand considerably on cooling. An alloy composed of—

Tin . .	48	Bismuth . .	9
Lead .	32½	Antimony .	10½

is specially suitable for *dabbing* rollers for printing cotton goods, and, possessing considerable hardness, it wears well.

§ 104. **Fusible Alloys containing Cadmium.**—Cadmium, like bismuth, has the valuable property of lowering the melting point of many alloys, some of which are readily fusible in boiling water. Cadmium does not render the alloys so crystalline and brittle as bismuth, many of its combinations being capable of being hammered and rolled. The chief use of cadmium is in fusible alloys, which are used as solders, for castings requiring a low temperature, and in dentistry for alloys for stopping hollow teeth.

Alloys of cadmium generally contain tin, lead, bismuth, and cadmium. Mercury is sometimes added to still further lower the melting point. The following table shows the composition and melting points of the more important cadmium alloys :—

	Cadmium.	Lead.	Tin.	Bismuth.	Melting point.
Lipowitz's alloy .	3	8	4	15	158° F.
Fusible alloy .	2	11	3	16	170° ,,
,, ,,	10	8	3	8	167° ,,
,, ,,	1	...	2	3	203° ,,
,, ,,	1	...	3	5	203° ,,
,, ,,	1	...	1	2	203° ,,
,, ,,	1	2	1	4	150° ,,
Wood's alloy .	2	4	2	5	160° ,,
Fusible alloy .	2	2	4	...	187° ,,
Type-metal .	22½	50	36	...	...

Lipowitz's alloy is prepared by melting the constituents together, and well stirring with a stick of hard wood before pouring. This alloy has a silvery-white colour and lustre, and can be bent short, hammered, and turned. It is well adapted for castings of delicate objects, and for soldering Britannia metal and other articles which cannot be strongly heated, and are of a white colour. It begins to soften at 140° F.

According to Hauer, the melting points of fusible alloys are proportionate to the atomic composition, thus :—

Formula.	Melting point.
1. Cd Sn Pb Bi	155·1° F.
2. Cd_3 Sn_4 Pb_4 Bi_4	153·5° ,,
3. Cd_4 Sn_5 Pb_5 Bi_5	150·0° ,,
4. Cd Pb_6 Bi_7	190·4° ,,
5. Cd Pb_3 Bi_2	193·0° ,,
6. Cd_2 Pb_7 Bi_4	203·0° ,,

The above formulæ correspond to the following percentage compositions :—

	I	II	III	IV	V	VI
Cadmium . .	17·31	13·6	14·3	4	9·7	8·9
Tin . . .	18·24	19	19	...	...	...
Lead . .	32·00	33·4	33·1	44	54	57·7
Bismuth . .	32·45	34	33·6	52	36·3	33·4

§ 105. **Fusible Alloys containing Mercury.**—An alloy containing

Lead	20
Bismuth . . .	20
Mercury . . .	60

is liquid at the ordinary temperature, and may be squeezed through chamois leather like mercury.

A fusible alloy for casts is made by adding a $\frac{1}{16}$ its weight of mercury to the alloy already mentioned, as in Rose's alloy. The new compound is fusible at the temperature of the human body. This alloy may be used for taking casts of certain portions of the human body after death, such as the ear. The animal substances are destroyed by a concentrated solution of caustic potash, and the metal remains.

An alloy for fusible teaspoons, etc., is composed of

Bismuth	8
Tin	3
Lead	5
Mercury	1 to 2

The following alloys are used for filling teeth :—

	I	II
Cadmium	25·99	21·74
Mercury	74·01	78·26

Any of the fusible alloys previously described may be used with the addition of a little mercury, and thus rendered still more fusible.

Alloy for Anatomical Preparations.—The following alloy melts at 169° F. and remains liquid at 140° F :—

Bismuth	53·5
Lead	17·0
Tin	19·0
Mercury	10·5
	100·0

CHAPTER VII

LEAD ALLOYS

§ 106. Lead forms alloys with most metals, some of which have been already considered. It is a soft metal, readily fusible, and generally tends to impart these properties to those metals with which it is combined. Some of its alloys are considered to be definite chemical compounds, which are capable of dissolving in an excess of lead. An addition of any other metal to lead hardens it and impairs its malleability. Zinc and iron only alloy with lead in limited proportions, the constituents separating according to their specific gravities. The most important alloys of lead are: pewter, soft solder, type-metal, and shot-metal.

§ 107. **Type-metal.**—An alloy for type-metal should be readily fusible, not show a great tendency to crystallise near the surface of the mould, sufficiently hard to prevent the crushing of the letters when printing, and capable of expanding on cooling so as to fill the moulds sharply.

To fulfil these conditions lead has generally been adopted as the base for type-metal, other metals being added to harden it, and impart the properties enumerated above. Zinc has been tried, but it does not alloy well with lead. Antimony answers the purpose fairly well, but if present beyond a certain amount, the alloys become very crystalline, hard, and brittle. Lead-antimony alloys not exceeding 15 per cent of antimony have the important property of expanding on cooling, which makes them very suitable for the manufacture of type. The alloy with 15 per cent of antimony is the most satisfactory as regards fluidity and expansion on cooling. It is more fusible than either of the constituent metals. However, this alloy of lead and antimony, notwithstanding the proper degree of hardness, has a vitreous structure, and imperfectly resists the action of the press, and of the scouring caustics. It was then tried to increase the resistance without losing the other qualities of the alloy. This result was obtained by the employment of tin or bismuth. The best proportion of tin appears to be from 6 to 8 per cent. A greater amount causes waste by oxidation; the alloy also becomes too brittle, with a great tendency for the tin and antimony to crystallise. Other metals have been added to lead and antimony for special purposes. Copper and iron in small quantity have been added to produce a hard resisting alloy for newspaper work. The following table gives the composition of several type alloys:—

ALLOYS USED FOR TYPE-METAL

	Lead.	Antimony.	Tin.	Bismuth.	Copper.	Zinc.	Other metals.
Printing types	4	1	...	...	...	...	...
,, ,,	7·5	2·5	...	...	·5	...	...
,, ,,	9	1	...	...	...	...	Arsenic ·5
,, ,,	64	8	12	...	...	16	...
Small types and stereotypes	9	2	...	2	...	...	...
Small types and stereotypes	16	4	5	...	...	...	...
Small types and stereotypes	3	1	...	...	...	...	..
Small types and stereotypes	5	1	...	...	...	...	...
Small types and stereotypes	10	2	...	1	...	...	...
Plates for engraving music, etc.	...	5	5	...	...	...	...
Plates for engraving music, etc.	...	2·5	7·5	...	...	...	...
Plates for engraving music, etc.	64	8	12	...	...	16	...
Plates for engraving music, etc.	60	2·5	37·5	...	...	...	...

The manufacture of type from the alloy by stamping or pressing is only adopted in certain cases, the types being generally cast. The alloys, being well adapted for castings, are employed for certain kinds of ornamental work.

An alloy for keys of flutes and similar parts of musical instruments consists of lead 2 parts, and antimony 1 part.

§ 108. **Lead and Arsenic.**—Arsenic unites readily with lead, forming alloys, which are hard and brittle if much arsenic be present. At the same time the fusibility of the lead is increased. A small quantity of arsenic in lead is used to form *shot-metal.* Shots are formed by letting drops of lead fall from a considerable height into water. It is found that the presence of arsenic enables the drops of metal to assume a spherical shape in thus falling.

The lead is melted in a cast-iron pot with oxide of arsenic and charcoal. The latter reduces the oxide to the metallic state, and the two metals unite to form an alloy. In England 10 parts of arsenic are allowed for 1100 parts lead. In France 8 parts of arsenic per 1000 parts of lead are considered sufficient. The purer the lead employed the greater is the quantity of arsenic required. If the amount of arsenic is too small the shots will not be spherical. Some manufacturers add other metals in small quantities, such as antimony and copper.

The molten alloy is poured into a perforated iron basin at the top of a tower and received in a vessel of water below. The perforations in the basins are regulated according to the size of the shot required, and each hole is three times its diameter distant from the next, otherwise two drops of lead in falling might coalesce. The water receiving the shot should be frequently changed, or it will get too hot. Some manufacturers prefer to have a layer of oil on the surface of the water, the shot retaining thereby its spherical shape better than when dropped directly into the water. To prevent the metal oxidising when removed from the water, a small quantity of (about ·25 per cent) sodium sulphide is dissolved in the water which receives the shot, and the drops of metal are thus coated with a film of lead sulphide, of a dark-gray colour, which is not affected by the atmosphere.

Instead of the method of dropping lead from the top of a tower, a plan for the manufacture of shot by centrifugal force has been introduced. The metal is poured in a thin stream upon a rapidly revolving disc, surrounded by a screen against which the shot is thrown. The centrifugal action divides the metal into drops, the size of which is regulated by the rapidity with which the disc revolves. The drops are stopped by the surrounding screen.

Mr. D. Smith of New York has devised a method of making shot, in which the molten metal falls through an ascending current of air, travelling with considerable velocity, so that the descending metal comes in contact with as many particles of air in a short tower as it would by the usual method in falling through a high tower.

§ 109. **Lead and Iron.**—These metals only alloy together in small proportions, and do not form combinations of much use in the Arts. In some experiments made by Guettier at Angers in 1848, lead to the extent of 2 to 3 per cent was thoroughly mixed with molten cast-iron, but the lead was almost entirely oxidised or deposited at the bottom of the mould. The cast-iron thus treated was harder, and its grains were flatter and without lustre. As soon as lead is introduced into molten cast-iron a certain agitation appears at the surface, and even through the whole bath, and the cast-iron seems more fluid. Guettier states that when thin or large pieces are to be cast, some founders throw a quantity of lead into the molten iron to prevent the metal solidifying too soon against the sides of the casting-ladle.

The want of affinity of iron for lead, and conversely, is made use of in separating lead from other metals having a greater affinity for iron. On the other hand, lead may be employed in separating iron from other metals, such as silver, for example. Thus, if lead is added in sufficient quantity to a fused alloy of iron and silver, it will combine with the silver, and the iron will swim on the surface of the bath.[1]

§ 110. **Lead and Copper.**—These metals do not unite in all proportions, and combinations are more easily produced when the copper is in excess. When the lead is in excess, the metal largely separates from the copper, or becomes much oxidised if the temperature be too high. In preparing copper-lead alloys, the copper should be melted first under a layer of charcoal, and then the lead introduced. The mixture should then be vigorously stirred with an iron rod for some time before pouring into the moulds. If the alloy be remelted, the union of the constituents becomes more intimate, the colour more uniform, the fracture more homogeneous, and the alloy stronger.

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[1] Guettier, *Guide Pratique des Alliages*, 1865.

When copper containing a little silver and an excess of lead is slowly raised to the melting point of lead, the latter liquates out, carrying with it the silver and a little copper. The residual copper also retains a portion of lead.

Lead is frequently added to certain copper alloys, such as brass, required for turning, as it renders them more fusible, and more easily worked with cutting or abrading tools. For those alloys, made on the large scale, into which it is desirable to introduce lead, it is best to previously prepare an alloy of equal parts of copper and lead, and add a portion of this mixture to the desired alloy, instead of using free lead for admixture.

An alloy of 4 parts lead to 1 part copper has been employed for casting large movable types.

§ 111. **Lead and Manganese.**—"When a mixture of 892 parts of peroxide of manganese and 2789 parts of oxide of lead are heated with charcoal in a carbon lined crucible, a homogeneous, compact, and malleable alloy is obtained, which can be rolled into sheets having great lustre when polished."[1]

§ 112. **Lead and Bismuth.**—These metals unite in various proportions by simple fusion. The alloys are malleable and ductile as long as the proportion of bismuth does not exceed that of lead; they are also more tenacious than lead. According to Guettier, "the alloy of bismuth 2, and lead 3 parts is ten times harder than pure lead. An alloy of equal parts bismuth and lead is harder and more malleable than lead. The ductility and malleability diminish with an increase of bismuth." An alloy of bismuth 1, and lead 2 parts is very ductile and malleable: Berthier gives its fusing point as 166° C.

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[1] Watt's *Dict. of Chem.* vol. iii. p. 534.

CHAPTER VIII

ALLOYS CONTAINING MERCURY—AMALGAMS

§ 113. Mercury or quicksilver readily unites with other metals, forming what are termed amalgams, some of which are liquid, while others are solid or semi-solid. As previously stated, the solid amalgams appear for the most part to consist of metals united in atomic proportions; and the liquid amalgams to contain a compound dissolved in excess of mercury. In all cases the bond of affinity between the constituents is somewhat feeble, for Joule has shown that many of those which contain equal numbers of atoms of the component metals may be partly decomposed by subjecting them to very great pressure, part of the mercury being forced out, and an amalgam containing a larger proportion of the other metals remaining behind. In many cases liquid amalgams after a time acquire a crystalline form, and the mercury in excess is separated. The crystallised body is the true amalgam, and is very probably a definite chemical compound. Mercury in small quantity is useful in alloys required to have low melting points, as in the case of fusible alloys used for stopping teeth. Amalgams of gold and silver were formerly much used for gilding and silvering, known as fire-gilding and silvering, because the mercury was volatilised by heat, leaving a deposit of gold or silver on the article. The process is still practised to a limited extent, when a very durable coating of gold is required.

Mercury unites readily with lead, zinc, tin, bismuth, cadmium, copper, gold, silver, magnesium, potassium, and sodium. The following metals unite with mercury with difficulty: iron, nickel, cobalt, manganese, and platinum in the compact state.

§ 114. **Lead-Amalgam.**—This substance may be formed by pouring molten lead into mercury, or by rubbing lead filings with mercury in a mortar by means of a pestle. The amalgam possesses a brilliant white colour, and remains liquid with as much as 33 per cent of lead, but it soils the fingers. The amalgam of equal parts can be crystallised, and a piece of lead plunged into this amalgam is found to be covered with crystals when it is withdrawn. The amalgam has a higher specific gravity than either of the metals, owing to the contraction they undergo in combining.

The presence of ·02 to ·025 per cent of lead improves the mercury for use in barometers and thermometers, as the latter metal has then not so great a tendency to form globules on the surface of the glass.

§ 115. **Zinc-Amalgam.**—Mercury and zinc unite to form white brittle alloys, which become pasty when the mercury predominates. Zinc combines readily with mercury when the latter is near its boiling point, and still more readily when mercury is mixed with molten zinc; 8 parts zinc to 1 part mercury is very brittle. 1 part zinc to 4 or 5 parts mercury form a brittle, pulverulent amalgam, sometimes used for rubbers of electric machines; but the addition of tin is preferable. Singer recommends 2 parts zinc, 1 part tin, and 4 to 6 parts mercury for this purpose. Zinc plates, used in galvanic batteries, are generally coated with mercury by first cleaning the zinc plate in dilute sulphuric acid, and then rubbing in the mercury with a brush or rag.

§ 116. **Tin-Amalgam.**—Mercury and tin combine at the ordinary temperature, and in all proportions when heated, especially by adding mercury to molten tin. An amalgam of 10 parts mercury to 1 part tin is liquid like mercury, but does not run so well. An alloy of equal parts is solid. Tin-amalgam has a tin-white colour, and, if the mercury is not in too great excess, is brittle and granular. The old method of silvering mirrors by placing the glass on a sheet of tin-foil covered with mercury is an instance of the application of tin-amalgam.

Dentists' Amalgam.—Tin-amalgam is used for filling teeth. 1 part of finely divided tin is rubbed together in a mortar with 4 parts of mercury. The excess of mercury is then removed by squeezing through a bag of chamois leather. A flexible mass is left which hardens in a few days. Another alloy is formed of 2 parts tin, 1 part cadmium and excess of mercury. The tin and cadmium are melted together and mercury added. The whole is then poured into an iron mortar, and well stirred with a wooden pestle till it acquires a soft buttery consistence; the excess of mercury is then squeezed off. The amalgam is soft and plastic when kneaded by the hand. See also fusible alloys, p. 266.

An amalgam of tin, silver, gold, and mercury is used as a cement for teeth. 1 part gold and 3 parts silver are melted, and 1 part tin is added. The resulting alloy is pulverised when hot, and then well kneaded with an equal weight of mercury.

Amalgam for Tinning.—Small iron articles can be tinned by first pickling bright in sulphuric acid, and dipping in melted tin-amalgam, then blanching in dilute acid, drying, and polishing.

§ 117. **Bismuth-Amalgam.**—Mercury is capable of dissolving a considerable quantity of bismuth without losing its liquid form, but a drop would be pear-shaped, and not globular like pure mercury. An amalgam of 4 parts mercury and 1 part bismuth may be used as a substitute for tin in tinning.

An amalgam of 3 parts mercury, 1 part lead, and 1 part bismuth is fluid, and has been used for adulterating mercury. It passes through chamois leather like pure mercury, but the drops are pear-shaped, which serves to detect the adulteration. Lucas states that mercury containing only $\frac{1}{8000}$ part of bismuth becomes coated with a black film when agitated in air.

§ 118. **Cadmium-Amalgam.**—Cadmium readily combines with mercury in the cold, but much more perfectly when mercury is added to molten cadmium. When mercury is completely saturated with cadmium, the alloy consists of 78·26 parts mercury and 21·74 parts cadmium, agreeing with the formula Hg_2Cd. Cadmium-amalgam is a tin-white, crystalline, brittle mass, which softens when moderately heated, and can be kneaded like wax. It is used by dentists for stopping teeth, but a better alloy containing tin has been previously described.

Evans's Metallic Cement is made by dissolving cadmium-amalgam (26 cadmium and 74 mercury) in excess of mercury, and pressing out the excess of mercury. This amalgam becomes very plastic by kneading.

§ 119. **Copper-Amalgam.**—Amalgams of copper and mercury are somewhat extensively used in the Arts. An amalgam containing 3 parts copper and 7 parts mercury becomes quite hard by keeping for a day or two. It has the property of softening and acquiring the consistence and elasticity of clay by pounding or kneading, and recovering its hard crystalline character when left to stand for a few hours. It was formerly much used for stopping teeth. Its density is the same in the hard as in the soft state, so that it does not expand or contract on hardening, and therefore fills cavities air-tight. It may be used for sealing bottles, glass tubes, etc., and as a cement for metals.

Copper-amalgam crystallises with great ease. It can be hammered or rolled, and admits of a good polish. It retains its lustre well in air, but is blackened by sulphur compounds, such as sulphuretted hydrogen. It becomes soft and flexible when placed in boiling water. Amalgamated copper plates are largely used for extracting gold and silver from certain ores of those metals.

Copper-amalgam may be formed (1) by immersing copper foil in a solution of mercuric nitrate. (2) By rubbing copper, which has been precipitated from its solutions by zinc, first with mercuric nitrate solution, then with mercury in a mortar. (3) Mercury placed in contact with the negative pole of a battery, and covered with a solution of copper sulphate, into which the positive wire dips, becomes saturated with copper. The chemical formula given to this compound by Joule is $CuHg$, or 63 parts copper to 200 parts mercury.

Ironier's Bronze consists of copper and tin with 1 per cent of mercury.

An alloy of 86·4 parts copper and 13·6 parts mercury is said to have a golden yellow colour, and to take a fine polish.

§ 120. **Gold-Amalgam.**—Mercury has a great solvent action on gold, and is capable of dissolving a considerable amount without losing its liquidity. The point of saturation, according to Guettier, is 2 parts of gold for 1 part of mercury, when it acquires a waxy consistence. Gold-amalgam may be produced at a very low temperature by exposing gold to the fumes of mercury. A piece of gold rubbed with mercury is immediately penetrated by it and becomes exceedingly brittle. Gold-amalgam dissolves in mercury forming a liquid mass. When this solution is strained through chamois leather, mercury passes through, together with a small quantity of gold, and there remains a white amalgam of pasty consistence. The amalgam, saturated with gold, when produced hot and allowed slowly to cool, becomes crystalline. By dissolving 1 part of gold in 1000 parts mercury, pressing through leather, and treating the residue with dilute nitric acid at a moderate heat, a solid amalgam Au_8Hg is obtained, which crystallises in four-sided prisms, retains its lustre in air, and does not melt, even when heated till the mercury volatilises.[1]

The liquid amalgams obtained by squeezing through chamois leather contain, at the ordinary temperature, ·126 per cent of gold; at 0° C. the percentage is ·110; at 100° C. ·650 per cent. These amalgams therefore behave like aqueous solutions. The residues left after the action of nitric acid on solid or liquid gold amalgams are not homogeneous, which proves that there probably exist definite compounds of gold and mercury dissolved in excess of mercury. A mixture of gold and mercury heated to a temperature a little above the boiling point of mercury, till its weight became constant, left an amalgam containing 10·02 to 10·5 per cent of mercury which corresponds to the formula Au_9Hg.

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[1] T. H. Henry, *Phil. Mag.* (4) vol. ix. p. 468.

The pasty amalgam of gold and mercury is the base of the various processes for gilding base metals by the old method, known as fire-gilding. For gilding copper, brass, etc., 8 to 9 parts of mercury to 1 part gold are used. The amalgam is prepared by heating the gold, cut up small, in a plumbago crucible to a red heat, then adding one-eighth or one-ninth of its weight of the above-mentioned amalgam, previously heated to boiling. The contents of the crucible are then well stirred with an iron rod, and poured into a large vessel cooled on the outside by water. If the amalgam is allowed to cool in the crucible, or if kept for some time after being poured into the cold vessel, it crystallises. The crystalline amalgam may, however, be restored to working condition by heating in a crucible with excess of mercury.

The articles to receive the deposit of gold are first cleansed by heating and dipping in dilute sulphuric acid, and sometimes in nitric acid; they are then dipped in a solution of nitrate of mercury, by which means they become coated with mercury, they are afterwards pressed upon the pasty amalgam, a portion of which adheres to it. The mercury is then expelled by heat and the gold surface polished. A mixture of bees-wax, red-ochre, copper acetate, and alum is then applied for the removal of the last traces of mercury, and to impart a redder shade to the surface. The articles are then burnished, washed with dilute nitric acid, then with water, and finally dried.

A native amalgam of gold in small yellowish crystals is found in California having the formula Au_2Hg_3 (gold 39·02 to 41·63 per cent, mercury 60·98 to 58·37 per cent). An amalgam of gold and silver is found in small white grains in New Granada containing 38·59 gold, 5 silver, 56·4 mercury per cent.

§ 121. **Silver-Amalgam.**—Silver and mercury unite slowly at ordinary temperatures, but much more quickly when at a red heat. The affinity of these metals for each other is nearly the same as that of mercury for gold, but with a greater tendency towards crystallisation. The more finely divided the silver, the more rapidly does amalgamation take place. Silver precipitated from its solutions by metallic zinc, then washed and dried, is in a very favourable condition for amalgamation. When such silver is thrown into a hot crucible containing mercury, combination rapidly takes place. By pressing the product in a chamois leather bag, the free mercury runs through and a soft white amalgam is left.

Silver-amalgam can be prepared by adding mercury to a solution of silver nitrate, the amalgam is precipitated in a crystalline form called a silver tree, or *Arbor Dianæ.* The silver solution should be somewhat acid, and not too concentrated. Joule gives the formula Ag_2Hg as the average composition of this amalgam. When the action is assisted by the aid of a battery, amalgams richer in silver are obtained.

Silver-amalgam varies in character according to its composition and mode of formation, being soft, granular, or crystalline. The soft amalgam obtained by uniting the two metals was formerly used for coating articles with silver in a manner similar to that described for gilding. A native compound, termed *amalgam*, and having the composition Ag_2Hg_2 or Ag_2Hg_3, is found in a crystallised state, and sometimes massive. Another amalgam, termed *arquerite,* is found in Chili, having the formula Ag_2Hg_6, or 13·5 silver and 86·5 mercury per cent.

§ 122. **Magnesium-Amalgam.**—[1] This amalgam is slowly formed by contact of mercury with pure magnesium in the cold, but quickly at the boiling point of mercury. In this amalgam the affinities of magnesium are exalted. An amalgam containing ·5 per cent magnesium swells up instantly in contact with air, and loses its lustre; it decomposes water readily. Magnesium-amalgam may also be prepared by covering sodium-amalgam with a solution of magnesium sulphate.

§ 123. **Sodium-Amalgam.**—Sodium combines rapidly with mercury at ordinary temperatures, the combination being attended with a hissing noise and vivid combustion. A piece of sodium forcibly thrown upon mercury is thrown out of the vessel with explosion, in consequence of the great heat produced. It can be prepared by melting sodium under petroleum, and introducing the mercury through a narrow glass tube. A silver-white solid amalgam is formed which must be kept under petroleum to prevent the oxidation of the sodium. Sodium-amalgam is also prepared by triturating the two metals together in a dry mortar, fitted with a cover, until the combustion ceases. With 30 parts mercury to 1 of sodium, it is tolerably hard under the file, and exhibits a crystalline laminar fracture. With 40 parts mercury to 1 of sodium the amalgam is still solid, but softer than the former. With 60 parts mercury to 1 of sodium it forms a stiff paste at 21° C.; 100 parts mercury to 1 of sodium produces a viscous mass; and 128 parts mercury to 1 of sodium is liquid.

Sodium-amalgam is used in the preparation of other amalgams. Metallic chlorides, such as those of silver and gold, for example, are decomposed by sodium-amalgam, and the reduced metal then unites with the mercury. Metals which do not readily unite directly with mercury may be amalgamated by the action of sodium-amalgam on certain solutions of their salts; thus: iron-amalgam is obtained by immersing sodium-amalgam, containing 1 per cent of sodium in a clear saturated solution of ferrous sulphate.

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[1] *Chem. Soc. J.* (2) vol. iv. p. 141.

Sodium-amalgam is used for the extraction of gold and silver from their ores instead of mercury. It is said to facilitate the amalgamation, and to prevent *flouring* of the mercury; *i.e.* it prevents the formation of oxide, sulphide, arsenide, etc., which would form a coat on the mercury and prevent contact with the gold or silver.

§ 124. **Potassium-Amalgam.**—Potassium unites with mercury with great violence at ordinary temperatures, and forms amalgams similar in properties to those of sodium.

CHAPTER IX

GOLD ALLOYS

§ 125. The properties which make gold so valuable in the Arts have been already mentioned in the introductory part of this work, and it has been shown that this metal is improved for manufacturing purposes by alloying with certain other metals, such as silver and copper, in small quantity. The great value of gold is the reason, in most cases, why the proportion of added metal should be small. Many metals not only reduce the value of gold, but impart qualities which destroy its high malleability and ductility, while others render the gold unfit for any useful purpose. With a few exceptions, it may be stated that the higher the value of a metal, the greater should be the proportion of this metal in the alloy.

Taking into consideration its high intrinsic value, gold may be considered the most perfect of all the metals, but it is necessary to impart to it a greater degree of hardness than it alone possesses, for the manufacture of coins, medals, jewellery, etc. Silver and copper are the metals invariably used for this purpose, and, when added in small quantity, do not materially alter the malleability and other working properties of gold, but increase its fusibility. The above remarks are only true when the silver and copper employed for alloying are practically pure, as a small quantity of lead, arsenic, antimony, etc., in the copper would considerably reduce the malleability and ductility of the alloy.

When gold is pure, or as nearly pure as it can be obtained for commercial purposes, it is commonly expressed as fine gold or 24 carat fine, the pound or 1000 parts being divided into 24 equal parts. Thus, 22-carat gold signifies that in 24 parts there are 22 parts gold and 2 parts of other metals. 9-carat gold likewise contains $\frac{9}{24}$ gold and $\frac{15}{24}$ other metals. The metal or metals added to gold are technically termed the alloy. The following table[1] gives the relative value of the different carats, and the amount of alloy to be added, taking 24 as the unit of fine gold and the mint price of purchase as 85 shillings per ounce troy:—

Quality.	£	s.	d.	Alloy to be added.
24 carats	4	5	0	...
23 ,,	4	1	5½	1 carat
22 ,,	3	17	11	2 ,,
21 ,,	3	14	4½	3 ,,
20 ,,	3	10	10	4 ,,
19 ,,	3	7	3½	5 ,,
18 ,,	3	3	9	6 ,,
17 ,,	3	0	2½	7 ,,
16 ,,	2	16	8	8 ,,
15 ,,	2	13	1½	9 ,,
14 ,,	2	9	7	10 ,,
13 ,,	2	6	0½	11 ,,
12 ,,	2	2	6	12 ,,
11 ,,	1	18	11½	13 ,,
10 ,,	1	15	5	14 ,,
9 ,,	1	11	10½	15 ,,
8 ,,	1	8	4	16 ,,
7 ,,	1	4	9½	17 ,,
6 ,,	1	1	3	18 ,,
5 ,,		17	8½	19 ,,
4 ,,		14	2	20 ,,
3 ,,		10	7½	21 ,,
2 ,,		7	1	22 ,,
1 ,,		3	6½	23 ,,

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[1] Streeter, *Gold*, p. 138.

The price of fine gold from refiners is a little higher than the mint price, by about 1s. per ounce for a single ounce, and proportionately lower for larger quantities. From this it will be seen that the cost of material to the manufacturer cannot be calculated merely on the amount of gold the alloy contains, and allowance must also be made for the quantity of alloy added, which is a consideration when much silver is used. Take 18-carat gold, for example. The price given in table is £3 : 3 : 9, the refiner's price would be £3 : 4 : 3, and assuming that the six parts of alloy consists of half silver and half copper, its cost will be 9d.; so that the 18-carat alloy costs £3 : 5s. per ounce before it is manufactured into articles.

§ 126. **Gold and Copper.**—These metals alloy well together in all proportions, and when the copper does not exceed 10 to 12 per cent the malleability is little altered—that is to say, 21-carat gold and upwards are practically as malleable as pure gold. Many of the alloys have a density less than the mean of that of the separate metals. The gold coinage of this country is made from 22-carat gold, or 916·6 parts gold to 83·3 parts copper, the alloying metal being copper. This is termed *standard gold.*

Standard gold is very largely used for the manufacture of wedding-rings. The makers formerly had to pay a duty of 17s. per ounce, one-sixth being remitted for loss in finishing. Wedding-rings of this quality must be *Hall-marked*, and this is required to be done when the rings are in an unfinished state, so that for every 6 ounces the maker paid for 5 ounces. Mourning-rings, watch-cases, etc., are also occasionally made of the above quality. The alloy of 20 parts gold and 4 parts copper is termed *brown-gold*, and is sometimes used by jewellers in decorative designs.

The gold-copper alloys used for coinage are generally accepted as being homogeneous, but doubts were raised upon the truth of this some years since by Mr. Booth of the United States Mint. Much evidence was afforded on this subject during the preparation of the Standard Gold Trial Plate, made in the Royal Mint in 1873. A mass of standard gold weighing 72 ounces was cast and rolled into a plate 37 inches long and 6·5 inches wide; portions were cut from different parts of it and assayed. The greatest variation between any two assays was $\frac{2}{10000}$, there being no evidence of concentration of the precious metal anywhere.

Professor Roberts-Austen[1] has conducted the following experiments to obtain evidence on the liquation of gold alloys. An ingot consisting of 984·7 parts gold and 15·3 parts silver was melted and cast into a spherical mould. From this sphere of gold a disc $\frac{3}{8}$ of an inch thick was cut, which weighed 31 ounces. It was then rolled in two directions at right angles and portions cut off for assaying. The result of 82 assays afforded no clear evidence of systematic rearrangement, for although there appeared to be an enrichment towards the upper part to the extent of $\frac{8}{100000}$, such small differences as existed in the assays made on metal taken from the same horizontal planes could not be regarded as being due to any definite redistribution of the metal. It may be taken as proved that gold of high standard does not, like silver, show any marked tendency to reject on solidification the baser metal with which it is associated. M. Peligot[2] has published the results of an investigation which point to the same conclusion.

§ 127. **Gold and Silver.**—These metals unite in all proportions, but do not generally appear to form true chemical combinations. Levol regards the union of these metals in equivalent proportions as being incapable of separating by gradual cooling. The alloys of gold and silver are harder, tougher, and more fusible than gold, and more sonorous and elastic than either metal taken singly. One-twentieth of silver is sufficient to modify the colour of gold, and is employed by jewellers to impart different shades of colour to gold. 27 to 30 per cent silver and 73 to 70 per cent gold form a green alloy. When the amount of silver exceeds 50 per cent the alloys are nearly white. The greenish-yellow cast of the sovereigns manufactured by the Sydney Mint, Australia, is due to the fact that the alloying metal used is silver, and not copper, as in the English sovereign. The Australian gold coins, however, are of the same standard in fineness, weight, and value as the English coins. Gold-silver alloys do not oxidise on exposure to air.

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[1] Annual Report of the Deputy-Master of the Mint, 1888.

[2] *Bull. de la Soc. d'Encouragement*, tom. iv. 1889, p. 171.

§ 128. **Gold, Silver, and Copper.**—These three metals are largely used by jewellers to form alloys more tough, malleable, and ductile than by using copper alone as the alloying metal. The alloy added to gold for manufacturing the old English guineas consisted of equal parts of copper and silver, which accounts for their yellow appearance. The guinea is of the same fineness as the sovereign, but differs in weight. It weighs 5 dwts. 9½ grains; and a sovereign 5 dwts. and a little over 3¼ grains; of which 4 dwts. 22¾ grains, and 4 dwts. 17 grains respectively are fine gold. Guineas have not been coined for circulation during the present reign.

[1] Gee gives in the following table the proportions of silver, copper, and gold used in jewellers' alloys:—

Carat.	Copper.	Silver.	Gold.
23	½	½	23
22	1	1	22
20	2	2	20
18	3	3	18
15	6	3	15
13	8	3	13
12	8½	3½	12
10	10	4	10
9	10½	4½	9
8	10½	5½	8
7	9	8	7

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[1] *Goldsmiths' Handbook*, pp. 41, 52.

With regard to 18-carat gold, Gee states that, "if properly cast, it is malleable and tenacious. It is also exceedingly ductile. A hardness is imparted to this quality of gold which admirably adapts it to the manufacture of jewellery of the highest order. There is perhaps a difficulty in preparing 18-carat gold not experienced in some other alloys." The general opinion is that the occasional want of cohesion is due to the copper employed, as by using a purer variety of copper the difficulty in working is diminished. The best alloy appears to be that given in the preceding table, for by increasing the amount of silver the colour of the alloy would suffer.

15-carat gold is also largely used for articles required to be made of *coloured gold*, as it is technically termed. The colouring is effected by dissolving out the copper from the exterior by suitable solvents, and leaving the surface with a colour like that of pure gold. It can thus be made to look equal to fine gold. It is easy to work, and the 9 parts of alloy give to the articles the requisite strength and hardness necessary to resist wear, and to retain their shape when subjected to various uses. This alloy can be Hall-marked as a guarantee of its proper quality. [1] Gee cautions purchasers of 15-carat gold against an inferior quality of gold introduced into the trade, and called 15 carat, bearing a stamp similar to the Hall-mark; however, this is not the Hall-mark, but the private mark of the manufacturer.

12½ to 13-carat gold is very extensively manufactured into all kinds of jewellery. This is the lowest quality that can be properly subjected to the colouring process, and retain a rich and uniform appearance without showing irregularities on the surface. The articles of the so-called 15-carat coloured gold, referred to above, were formerly made of this quality.

12-carat gold is known in the jewellery trade as the best of the *bright golds*—that is, qualities which cannot be properly coloured, and therefore show the true colours of the alloys of which they are composed, and not a surface of superior metal, as is the case in coloured gold articles, which have a much richer appearance than bright gold, and consequently are in much greater demand. The 12-carat alloy, using the proportions given in the preceding table, is malleable and ductile, and tolerably soft, so that it possesses good working qualities. It may be Hall-marked as a guarantee of its purity.

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[1] *Goldsmiths' Handbook*, p. 46.

10-carat gold is similar in physical properties to the 12-carat alloy, but has a different shade of colour, owing to the different proportions of the constituent metals. This quality is not Hall-marked.

9-carat gold is used for manufacturing articles of almost every description of jewellery, and when up to standard fineness may be Hall-marked. The quality most extensively employed is somewhat below the standard, this being the extreme limit that will stand the test of nitric acid without exhibiting signs of corrosion. [1] Gee states that "9-carat gold of the mixture given in the preceding table, p. 293, will stand more than ordinary treatment from the hands of the workman, and may be touched and removed from the annealing-pan while still red-hot, without injury to any subsequent manipulation of it; it may also be quenched at any degree of heat in pickle and water, if any advantage is likely to accrue from it; but we strongly object to the continuous quenching of gold alloys at every subsequent process of annealing—partly because, every time the metal is quenched in sulphuric acid pickle, a portion of the base metal in these low qualities is dissolved."

9-carat alloys are sometimes alloyed with zinc, or spelter, as it is generally termed in the trade, in small quantity; but it must be very sparingly used, or the alloys will be hard, brittle, and difficult to work, and, moreover, more readily acted upon by acids.

8-carat gold and qualities inferior to this are harder, and require more careful working than the higher alloys. They are more liable to become brittle and to break, unless carefully annealed at the proper stages. 8-carat gold may be made to withstand the acid-test by using more silver than that given in the table (p. 293), but the alloy is paler to the eye. This quality works up well if proper judgment is exercised in the manipulation.

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[1] *Goldsmiths' Handbook*, p. 48.

§ 129. **Gold, Silver, Copper, and Zinc.**—Mention has already been made of the fact that zinc is sometimes employed in gold alloys used by jewellers. It is generally used in the form of brass, termed *composition*, which varies in the proportions of its constituents with different makers, and may be typically represented as containing 2 parts copper to 1 part zinc. The effect of zinc on gold is to harden it and make it brittle. An alloy of 11 parts gold to 1 part zinc resembles pale yellow brass in colour, and does not tarnish in air. Gee gives 17 per cent of zinc in gold as the maximum amount that can be safely worked. When silver, in ordinary jewellers' alloys, is partly replaced by composition, the alloy appears of a deeper colour, and may be made to resemble one containing a higher standard of gold, but it is more difficult to manipulate, and more liable to change colour, depending of course on the amount of composition used. (See also gold solders, p. 312.)

§ 130. **Gold and Tin.**—These metals appear to mix in all proportions forming, for the most part, brittle alloys. Guettier states that when the tin does not exceed 8 per cent, the alloys have a certain amount of ductility. The colour is yellow, pale, or white, according to the quantity of tin present. Like the alloys of gold and zinc, the union of the two metals produces contraction — that is, their specific gravities are in excess of the mean of their constituents.

§ 131. **Gold and Lead.**—These metals unite readily in all proportions, producing very brittle alloys, which are harder and more fusible than gold, and without any utility in the Arts. $\frac{1}{2000}$ part of lead melted with standard gold, and the alloy cast into a bar, can be broken with a slight tap with a hammer; the colour is also altered to orange-brown, and experiments have shown that the tenacity of the metal is reduced from 18 to 5 tons per square inch. All the alloys of gold and lead expand on alloying, and this is greatest when copper is present and the quantity of lead is small. The greatest expansion, according to Guettier, takes place when the lead is only ·001 of the alloy. An alloy of 11 parts gold and 1 part lead has the colour of gold and the fragility of glass. (See also p. 71.)

§ 132. **Gold and Bismuth.**—These metals alloy well together in various proportions forming bodies having the appearance of brass, when the gold is in excess. Bismuth is highly injurious to gold, making it hard and brittle.

§ 133. **Gold and Antimony.**—Antimony has a strong affinity for gold, and dissolves it rapidly. Melted gold dissolves the vapour of antimony, and when this metal is present in gold in very minute quantity it renders the gold brittle. An alloy of 9 parts gold to 1 part antimony is white, brittle, and has a granular fracture. $\frac{1}{2000}$ of antimony in gold hardens it, and considerably impairs its malleability. Antimony may be largely removed from gold by heat.

§ 134. **Gold and Arsenic.**—Arsenic, like antimony, readily unites with gold, and is equally injurious when present in minute quantity. The alloys are grayish-white when much arsenic is present, hard, more fusible than gold, and very brittle.

§ 135. **Gold and Iron.**—Iron in small quantity is sometimes added to gold alloys for ornamental purposes, in order to impart a characteristic tint. Gold and iron combine in all proportions, the former increasing the fusibility of the latter. Gold in small quantity does not seem to impair the qualities of iron. Guettier states that an alloy of equal parts gold and iron is grayish-white, brittle, and slightly magnetic. The alloy containing $\frac{1}{12}$ iron is pale yellow, and becomes grayish-yellow when the iron is increased to $\frac{1}{6}$. This is known to some jewellers as *gray gold*. Gee gives 18 parts gold to 6 parts iron as the proportions of *blue gold*. With regard to this alloy, he directs that the gold should be melted first, and then iron wire in small pieces introduced successively into the molten metal. When cast it must be hammered on the edge and annealed, in order to give a closer grain, and prevent cracking during the rolling. This process may be wisely repeated upon the surface, and the ingot again annealed. The alloy may then be safely wrought into wire or sheets.

§ 136. **Gold and Platinum.**—These metals unite to form ductile and elastic alloys, but require a high temperature to effect their combination in consequence of the high melting point of platinum. This circumstance, combined with the effect the platinum possesses of making the colour of gold paler, considerably limits the application of these alloys for jewellery. Platinum, however, like gold, is not acted upon by nitric acid, or by the atmosphere. An alloy of 7 parts platinum and 3 parts gold is infusible in the strongest blast-furnace, but with a greater proportion of gold fusion takes place. 2 parts platinum and 1 part gold form a brittle alloy. 1 part platinum and 1 part gold form a malleable alloy of a pale gold colour. Clarke states that an alloy of 9·6 parts gold and 1 part platinum has the colour of gold and the density of platinum.

It is well known that in gold-platinum alloys certain portions of the constituents separate and become concentrated either in the centre or in the external portions of the solidified mass. Mr. Edward Matthey[1] has investigated this subject; he cast gold containing platinum into a spherical iron mould, 3 inches in diameter, and cut the metal so obtained into halves. The shrinkage was so great that the spheres had to be cast several times in order to get them solid. Portions were then taken from different parts of the spheres and assayed.

A. Composed of about 880 gold and 050 platinum.

B. Composed of about 700 gold and 120 platinum.

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[1] *Proc. Roy. Soc.* 13th February 1890.

In the sphere A the maximum difference between the gold percentage is a variation of 032, viz. 887 on the outside against 883·8 at the centre of the alloy; and in the platinum 047·5 on the outside against 052·5 at the centre, showing an extreme variation of 005.

In the sphere B the maximum difference between the gold percentage is a variation of 041, viz. 732·4 on the outside against 694·1 at the centre of the alloy; and in the platinum 122 on the outside against 166 at the centre, giving an extreme variation of 044.

These results show indisputably that *the platinum in cooling liquates from the gold and becomes concentrated towards the centre of the alloy.*

The above experiments were made on gold-platinum alloys containing silver and copper. In order to prove whether a similar liquation takes place with alloys containing gold and platinum alone, 900 parts of fine gold were repeatedly melted with 100 parts of pure platinum, and then cast as before. The result showed that the exterior contained 900 gold and 098 platinum, against 845 gold and 146 platinum at the centre of the sphere.

§ 137. **Gold and Palladium.**—Several alloys of these metals have been formed, the combination taking place without incandescence. 1 part palladium and 1 part gold form a gray alloy, having the colour of wrought-iron, less ductile than either of the component metals, and of a coarse-grained fracture. 1 part palladium and 4 parts gold yield a white, hard, ductile alloy. 1 part palladium and 6 parts gold is almost white. Alloys of gold, silver, copper, and palladium have been used for bearings of the arbors in good watches; the colour is brownish-red, they are as hard as iron, do not rust, and cause the minimum of friction. The following is a typical alloy for watches: gold 37·5, copper 27·1, silver 22·9, palladium 12·5. Berzelius analysed a native alloy from Porpez, containing 85·98 gold, 9·85 palladium, and 4·17 silver per cent.

§ 138. **Gold and Aluminium.**—An alloy of gold, copper, and aluminium, known as Nürnberg gold, is used in the manufacture of cheap gold-ware. Its colour resembles that of gold, and it is said to remain unchanged in air.

§ 139. **Coloured Golds.**—Jewellers and goldsmiths use a variety of gold alloys for purposes of ornamentation, so as to produce a number of different shades of colour in the same article. For example, red and white are employed for flowers, green for leaves, and yellow for stems, sprays, etc. The following table gives the composition per cent of alloys most in use :—

Colour.	Gold.	Silver.	Copper.	Iron.	Platinum.	Cadmium.
White . .	...	100	...	...	...	...
,, . .	...	...	...	...	100	...
Gray . .	85·7	8·6	...	5·7	...	...
,, . .	83·3	...	...	16·7	...	...
,, . .	72·5	27·5	...	...	...	...
Green . .	75	25	...	...	...	...
,, . .	75	16·6	...	...	...	8·4
,, . .	74·6	11·4	9·7	...	...	4·3
,, . .	75	12·5	...	...	...	12·5
Pale yellow .	91·67	8·33	...	...	...	...
,, .	91·67	...	...	8·33	...	...
Very pale .	50	50	...	...	...	...
Yellow . .	100	...	...	...	...	...
Deep yellow .	90	...	10	...	...	...
,, .	53	25	22	...	...	...
Red . .	75	...	25	...	...	...
Dark red .	50	...	50	...	...	...
,, .	25	...	75	...	...	..
Blue . .	75	...	...	25	...	...
,, . .	66·7	...	...	33·3	...	...
Japanese blue gold	1 to 10	...	99 to 90	...	...	...

The necessary precautions for the preparation of gold alloys containing iron have been given (see p. 297). The alloys of gold, silver, and copper call for no special remarks here. The alloys containing cadmium given in the above table are malleable and ductile. It should be borne in mind that cadmium is a volatile metal like zinc, and should therefore be added after the other metals are melted under a layer of charcoal. Much depends upon the rapidity with which it is added, and the perfect incorporation of this metal in the alloy will also depend on the vigour with which the metals are quickly stirred, preferably with a charcoal stick. In any case, some of the cadmium volatilises, and a little more than the stated amount should be added, to compensate for this loss. The term *coloured golds* in the above heading does not refer to the chemical process of colouring, which will be referred to hereafter.

§ 140. **Standard Gold.**—In most countries there are gold alloys of a certain degree of fineness, fixed by law, and used as the national standard of value for coinage. They nearly all consist of gold and copper, the latter metal being necessary to enable the gold to resist the wear to which it is subjected in commerce. Notwithstanding the hardening effect of the base metal, coins wear considerably when frequently used, causing them to become light in weight. An English sovereign weighs 123·27,447 grains, and remains a legal tender till it is reduced below 122·5 grains, the difference between these two weights being the remedy allowed by English law for abrasion or loss by wear.

Besides the standard fineness for coins, there is also a legal weight, fixed according to the regulations of the Royal Mint. 1 lb. troy of standard gold is worth £46 : 14 : 11, and if a person were to take 1 lb. troy of standard gold to the Mint to be coined, he would receive 46 sovereigns, 1 half-sovereign, and nearly 5 shillings in return without being charged anything for the coinage of the gold. Hence, standard gold contains nominally and intrinsically its full value of gold. The coinage is conducted with great exactness by the officers of the Mint with respect to weight, and the extreme accuracy with which they are compelled to work is seen by the following table :—

Coin.	Weight in grains.	Remedy in grains.
Sovereign	123·27,447	0·20,000
Half-sovereign	61·63,723	0·10,000

The remedy, of $\frac{1}{5}$ and $\frac{1}{10}$ of a grain respectively, is the difference allowed to the Deputy-Master of the Mint, between the standard and real weight of the manufactured coins; and he invariably confines himself well within these limits.

The British standard for gold coins is 22 carat or 916·666 parts of gold and 83·333 parts of copper per thousand, the remedy being ·002 or $\frac{1}{500}$ of a grain. The old guinea is of the same standard as the sovereign, but contains a little silver and less copper.

The standards of different countries are given in the following table:—

Name.	Gold per 1000 parts.	Carat.
Egyptian, Mexican, Spanish, Philippine Islands	875	21
Old German coins (pistoles) .	895	21·5
German coins	900	21·6
Austrian crowns		
French coins		
Belgian ,,		
Italian ,,		
Swiss ,,		
Spanish ,,		
Greek ,,		
United States coins		
Japanese ,,		
Chinese ,,		
Russian (new)		
Prussian Freidrich'sd'or .	902	21·65
British coins	916·6	22
Prussian (old) coins		
Portuguese ,,		
Turkish ,,		
Brazilian ,,		
Dutch ducats	982	23·57
Austrian ,, ...	986	23·66
Hungarian ,, ...	989	23·74

Previous to the reign of Charles II all the coin of this realm was made by hand—by forging pieces of gold to the proper thickness required for the coins, then cutting them into squares a little larger than required for the different sizes. The corners were afterwards removed from the squares, and the pieces rounded to the proper size, when they were adjusted to the desired weight for circulation. These round blanks were then placed consecutively between steel dies, containing the pattern of the intended coin; the upper die was then struck with a hammer to produce the impression.

The different alloys used by jewellers in this country have been already discussed. In France 18, 20, and 22 carat gold are assay-marked. In Germany 18, 14, 8, and a 6-carat alloy, termed *joujou gold*, used for electro-gilding, are recognised. Austria has three legal standards: No I 326, No. II 545, No. III 767 degrees of fineness per thousand.

Pforzheim Gold-ware (German)

Ordinary ware (joujou)	130 to 250 parts gold per 1000
Finer quality	563 ,, ,, ,,
Finest quality	583 to 750 ,, ,, ,,

§ 141. Since the introduction of the decimal system, the method of expressing the fineness of gold alloys in thousandths has been gradually gaining ground. Its simplicity, over the old system of carats and grains, is its great recommendation. The carat consists of 4 carat-grains. The following table shows the equivalents of carat-grains and carats in thousandths:—

1 grain =	10·414	6 carats =	250·000
2 ,,	20·828	7 ,,	291·666
3 ,,	31·242	8 ,,	333·333
4 ,,	41·66	9 ,,	374·999
1 carat =	41·667	10 ,,	416·667
2 ,,	83·334	11 ,,	458·630
3 ,,	125·001	12 ,,	500·000
4 ,,	166·667	13 ,,	541·667
5 ,,	208·333	14 ,,	583·333

15 carats =	624·555	20 carats =	833·333
16 ,,	666·667	21 ,,	874·999
17 ,,	707·333	22 ,,	916·666
18 ,,	750·000	23 ,,	958·333
19 ,,	791·666	24 ,,	1000·000

Preparation of Gold Alloys

§ 142. The gold and silver, as purchased from the refiner, is sufficiently pure, in most cases, for the purposes of the manufacturer. Various kinds of copper are used, but in all cases it is required to be of excellent quality. The impurities most likely to be present are: iron, arsenic, antimony, and sulphur, the three latter being specially hurtful. Persons using copper for alloying should specify that these elements be absent, or only present in very minute quantities. Arsenic and sulphur are much more commonly present than antimony. [1] Dr. A. S. Taylor states that he found arsenic in not fewer than forty samples of copper, employed in the form of wire, sheet, gauze, etc. He further states that he found arsenic in two out of five specimens of electrotype copper. He does not appear to have examined any specimens of best-selected copper. It should be stated that the better qualities of commercial copper are now superior in purity to those manufactured forty years ago.

Gold and its alloys should be melted in good plumbago crucibles, which, if carefully annealed in an inverted position before use, will last a great number of times. The crucible should be covered with a lid. A new pot should be rubbed inside with charcoal powder, to prevent any particles of metal adhering to it. Some jewellers lay stress on the manner in which the metals are placed in the crucible, and it is a good plan to have the gold on the top, as it does not oxidise, and to some extent protects the copper, especially when covered with a layer of charcoal. In making alloys of which zinc is a constituent, this metal must be added after the other metals are melted, on account of its volatile nature. When the mixture is melted the whole must be vigorously stirred with an iron rod (previously made red-hot), in order to promote more intimate union between the constituents of the alloy. The metal is then ready for pouring into the mould if the proper temperature has been attained.

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[1] *Research on Arsenic, Antimony,* etc., p. 28.

Gold alloys are cast either into iron or sand moulds according to the purpose for which the metal is designed. Jewellers rarely use moulds for shaping the articles, except such as have considerable thickness, such as seal-rings, and articles with high relief. For small gold work the cuttle-fish bone is used as a mould, the pattern being pressed in, as in the case of sand. Sometimes the process is simply performed by rubbing two pieces of bone quite flat on a smooth stone, and then cutting in one of the pieces the shape required, leaving a hole through to the edge by which to pour in the metal.

For the most part gold is cast into ingot-moulds, and subsequently rolled into sheet, or rolled and drawn into wire. The various precautions, referred to in a previous part of this work, when treating of the casting of metals, apply in a great measure to gold alloys. The mould must be dry, suitably warmed, and blackened or greased to prevent the metal sticking. If the mould be too cold or too hot, the metal will spit, and thus incur loss of gold. Care must be taken not to let the charcoal or dross run with the metal into the mould; carelessness in this respect is often the cause of faulty castings. The dross, etc., may be prevented from passing into the mould with the gold by using a thin piece of flat wood, held in the left hand; poplar wood is preferred, because it burns away very slowly. Many defects arise from the use of bad charcoal-powder, which is sometimes contaminated with coal-dust. The latter may be detected by washing a portion, when the coal will impart a colour to the water, while water filtered from good charcoal will be perfectly colourless.

Gold sometimes cracks during rolling, due to its brittleness, from the presence of impurities. Many substances are recommended and used for the toughening and brightening of jewellers' gold alloys, consisting, for the most part, of substances containing chlorine, such as common salt, bichloride of mercury, and sal-ammoniac. Common salt is not advisable, as it produces a very liquid slag, which is liable to run into the ingot-mould along with the metal, making the ingot irregular and full of small holes. The same remarks apply to borax. Bichloride of mercury is very useful when the brittleness of the gold arises from the presence of lead or tin; the fractured surface of the bar then presents a close grain, of a pale yellow colour. In most cases sal-ammoniac is the best agent for producing tough gold. The sal-ammoniac, like the mercury chloride, is a volatile substance, and partly vaporises, while another portion is decomposed into ammonia and hydrochloric acid. The latter probably acts on the base metals, yielding up to them its contained chlorine and forming volatile chlorides. Thus, no slag is left to run into the moulds and interfere with the ingot of purified metal. In most cases a very small amount of this flux is required, and, indeed, a great excess will be injurious. In all cases, where gold alloys containing copper are melted for toughening, a little charcoal should be added along with the chloride employed.

In making gold alloys, the ingredients of which do not contain sufficient impurities to interfere with the toughness of the gold, it is not advisable to use anything else except a little powdered charcoal, which forms a protective coating and prevents the oxidation of the copper.

In melting precious metals the quality of the coke employed is not such a matter of indifference as some manufacturers suppose. The following observations by Mr. C. Tookey, formerly assistant assayer at the Japanese Mint, bear on this subject.

[1] In the Imperial Mint at Osaka, Japan, bars of gold from San Francisco were frequently converted into standard

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[1] Percy's *Metallurgy*, Gold and Silver, Part I. p. 489.

metal by melting them with the requisite proportion of Japanese copper to produce an alloy containing $\frac{900}{1000}$ of gold. In melting one particular consignment there was an unusual loss. No good reason could be assigned in the Melting Department, but on investigation Mr. Tookey found that the plumbago muffles and stirrers used in the operation were coated with minute particles of the gold alloy. It appeared as though the particles had been projected from the surface of the molten metal by the escape of a gas. Mr. Tookey had often watched a similar phenomenon when pots containing a silver-copper alloy were removed from the furnaces previous to pouring. While one of these pots, holding 2500 ounces, was cooling on the floor of the melting room to the proper temperature, a strong effervescence took place at the surface of the metal, projecting it in most minute particles, which were deposited on the floor of the room. During the effervescence there was a powerful smell of sulphurous acid, which had no doubt been absorbed or occluded by the metal, while the pot containing it had been exposed, at a high temperature, to the products of combustion of coke containing much sulphur.

The size of the cast bars vary according to the branch of the jewellery trade for which they are required. Locket-makers cast the gold in broad and thin plates. Chain-makers cast their metal in long and tolerably thick strips, which, when rolled to about Nos. 10, 11, or 12 of the Birmingham wire gauge, are annealed and cut into strips in the slitting mill, when they are drawn into wire.

An ordinary jeweller's melting furnace is a wind furnace about 9 inches square and 18 inches deep, lined with fire-brick. The draught-hole is 6 by 3 inches, and the ash-pit should have a capacity at least equal to that of the furnace. The bars are 10 inches long, 1¼ inches wide at the top, and gradually taper towards the bottom. The furnace must be connected with a chimney at least 40 feet high, in order to obtain an active and strong draught. The furnace mouth is closed by two fire-bricks, each of which is clamped by a piece of flat bar-iron, well wedged on. The draught is regulated by a suitable damper fixed in the flue. Coke is the fuel generally employed. This should be of good quality and practically free from sulphur.

The furnaces used for melting gold for coinage are of larger dimensions than the one just described, and correspond in capacity and arrangement to those used for ordinary brass melting (see Figs. 7-12) described under the head of "brass." The gold is sent from the Bank of England to the Mint in ingots of 400 ounces each. The crucibles are made of plumbago and are capable of melting 1200 ounces of standard gold. The pots are heated previous to the introduction of the charge, to prevent them cracking or flying when containing the precious metal. To ascertain whether a crucible is sound a cold bar of iron is put to the bottom, when, if any cracks exist, they will become visible. When the mixture of gold and copper is melted it is thoroughly stirred with an iron rod, then poured into ingot-moulds.

The plates of gold are then assayed, two assays being made by two different men for each plate, and the correct standard thus determined. If found correct, the plates are then weighed and rolled to the desired size for cutting out the blanks.

§ 143. *Preparation of Pure Gold.*—The following method has been adopted for the manufacture of the pure gold Trial-Plate now in the custody of the Warden of the Standards. Fine gold is dissolved in aqua-regia, the excess of acid driven off, and alcohol and potassium chloride added to precipitate traces of platinum. The chloride of gold is then diluted with distilled water in the proportion of half an ounce to the gallon, when the solution is allowed to stand three weeks. The solution is then carefully syphoned off, and oxalic acid in crystals added from time to time until the solution is colourless, the precipitation of the gold towards the end being aided by a gentle heat. The spongy gold so obtained is washed repeatedly with hydrochloric acid, distilled water, ammonia water, and lastly with distilled water. It is then melted in a Picardy crucible with a little pure bisulphate of potash and borax, and poured into a stone mould. The Trial-Plate prepared in this way weighed 70 ounces and was of the average purity of 999·96 parts of gold per 1000.

§ 144. *Refining of Gold.*—The gold employed for coinage, when it does not contain more than 10 per cent of silver, is usually purified by Miller's process with chlorine gas. This process consists of melting the impure gold in a clay crucible, which has been glazed inside with borax, and passing chlorine through the molten metal by means of a clay pipe. The chlorine combines with the silver to form silver chloride, which rises to the surface of the molten metal, whilst the chlorides of base metals which may be present, such as zinc, bismuth, antimony, arsenic, etc., are volatilised. A layer of borax is placed on the top to prevent the silver chloride from being volatilised. The gold thus refined varies in purity from 991 to 997 in 1000 parts, which is purer than ordinary fine gold.

Dr. J. C. Booth, of the United States Mint, has discovered a general method of toughening gold and silver which he described to the American Chemical Society a few years back. Some time ago Mr. Booth found that a quantity of brittle gold accidentally melted with some tough gold in a crucible had rendered the whole mass very brittle, crystalline in fracture, and therefore useless for coining. The whole was toughened by him in one and a half days at a trifling cost by the new process. The 75,000 ounces of gold were divided into 14 "melts" of 5400 ounces each, and each melt separately toughened. The ingots, which could be broken into pieces by striking them on the edge of a wooden box, were put into the crucible with soda ash and anhydrous fused borax, in the ratio of one or two ounces to a melt, until the crucible was nearly full. After melting it appeared as a quiet mass of metal covered with a viscid slag, disposed to swell and puff.

A few crystals of saltpetre, say one or two ounces, were then dropped into the centre of the metallic surface, and as they melted, their spreading out over the whole surface was aided by the concentric motion of the bottom of a small crucible. The moment the visible oxidising action began to slacken, the melter skimmed off, by a small blacklead dipping crucible, the fluxed matter as rapidly as was consistent with the care necessary to avoid taking up metal. The remainder in the melting pot was the toughened metal.

§ 145. **Gold Plating.**—This consists of joining a bar of gold and gilding or other metal together by *sweating* or soldering. A bar of gold of a desired quality and a bar of base metal are first made perfectly flat under a stamp or press; then the surfaces to be joined are filed or scraped clean; borax is next prepared and well rubbed over the surfaces. The two bars of metal are firmly secured together by iron wire, placed in a muffle, and the temperature raised nearly to the point of fusion when the metals unite into one compact bar. This is termed joining by "sweating."

Another method, which is more generally adopted, is to join the two bars by soldering. The two bars are prepared as in the former case. The metal-bar, being larger than the gold-bar, supports the pieces of solder, which are placed along one side, and half-way along each end. The whole is then strongly heated in a muffle until the solder melts, and joins them together. These compound bars may be rolled, stamped, spun, or otherwise manipulated, as though they had been melted to form one homogeneous mass. The gold follows the reduction of the base metal during the processes of rolling, etc., and retains the relative proportion of thickness between them.

HARD SOLDERS FOR GOLD WORK

§ 146. With respect to hard solders, it may be taken as a general guide that the more nearly the solder approximates in composition and properties to that of the metal to be soldered, the more perfect will the union of the two parts be, and the stronger the point of juncture. On the other hand, the greater the difference between the melting points of the solder and the metal to be soldered the easier will the operation be. In all cases it is necessary that the solder should have a lower melting point than the metal to be soldered.

Solder is said to be "hard" when it has a high melting point, *i.e.* at or above a red heat, and is literally hard with regard to its power of resisting the pressure of a cutting or abrading tool. As the melting point of the solder alloy is lowered by the addition of an easily fusible metal, or by the addition of a greater amount of the more fusible constituents of the mixture, the solder is said to be "easy" or softer.

Gold solders are made in a great variety of degrees of softness and hardness by the addition of different proportions of a more fusible metal, such as silver, to the gold. Thus, in 18-carat gold, for example, the solder may be made from the 18-carat alloy by adding a certain proportion of silver and copper, so as not to materially alter the colour. If the solder is made too poor in quality, the articles will not colour properly. Coloured gold solders contain 1 part of silver to 4, 5, or 6 parts of alloyed gold according to the degree of fusibility desired. [1] Gee gives the following tables for coloured-gold solders :—

Description.	Fine gold.	Fine silver.	Copper.
Best solder . .	12½ parts	4½ parts	3 parts
Medium solder .	10 ,,	6 ,,	4 ,,
Common solder .	8½ ,,	6½ ,,	5 ,,

These solders may be rolled thin, and cut with the shears and pressed into suitable pieces termed "pallions," or filed into dust, according to the needs of the workman.

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[1] *Goldsmiths' Handbook*, pp. 136, 217. 1881.

TABLE OF COLOURED-GOLD SOLDERS SUITABLE FOR THE FOLLOWING PROCESSES

Description.	Fine gold.			Fine silver.			Copper or compo.			Total.			Value per oz.		
	oz.	dwt.	gr.	oz.	dwt.	gr.	oz.	dwt.	gr.	oz.	dwt.	gr.	£.	s.	d.
Dry colouring	1	0	0	0	6	0	0	4	0	1	10	0	2	18	0
French ,,	1	0	0	0	8	0	0	7	0	1	15	0	2	10	0
London ,,	1	0	0	0	11	0	0	9	0	2	0	0	2	5	0
Birmingham ,,	1	0	0	0	12	12	0	10	0	2	2	12	2	2	6
German ,,	1	0	0	0	13	0	0	12	0	2	5	0	2	0	0
Best bright	1	0	0	1	1	0	1	0	0	3	1	0	1	10	0

The following table gives the composition of various solders for alloys of different standards :—

	Gold.	Silver.	Copper.	Zinc.
Hard solder for gold	10	5	...	1·00
Hard solder for 16-carat gold .	9	2	1	...
Easier ,, ,, ,, . .	12	7	3	...
Solder for about 14-carat gold .	3	2	1	...
,, ,, ,, ,, . .	2	0·5	0·5	...
,, for less than 14-carat gold .	1	2	1	...
,, ,, ,, ,, .	1	2	...	...
,, ,, ,, ,, .	1	...	2	...
Very easy solder	11·54	54·74	28·17	5·55

§ 147. **Colouring of Gold.**—This operation consists of imparting a colour to gold articles after every other process has been completed. Its object is to give to alloyed gold all the appearance of fine gold itself by dissolving out the base metal from the surface of the articles and leaving a facing of gold of a deep rich colour. Two distinct modes of colouring are adopted by jewellers, termed respectively *dry colouring* and *wet colouring*. The latter is most frequently practised, as the former cannot well be applied to gold inferior to 18 carat.

Wet Colouring.—The ingredients of the mixture employed in this process have a powerfully solvent action on the base metal with which the gold is alloyed, and a weaker action on the gold itself, so that the article loses weight in direct ratio to the length of time it is submitted to the colouring process, and this loss is greater as the gold is lower in quality. [1] Gee states that the colouring is hastened and the loss in weight reduced to a minimum by using old colouring liquid, and he assumes that the dissolved gold is, to some extent, deposited again on the article, because the loss in weight of some common qualities of gold was found to be very little, and the amount of gold recovered from the spent colouring liquid very small indeed. This statement is in accord with the well-known fact that in any liquid in which a metal, say copper, is electro positive to the metal in solution, say gold, the latter is deposited on the former.

Many different mixtures are used for colouring gold, some of which will be afterwards given in tabular form. The following has been supplied to the author by an experienced Birmingham jeweller, which he has found to be effective :—

Potassium nitrate . . .	12 ounces
Common salt	6 ,,
Hydrochloric acid . . .	3 ,,

The nitrate and salt are pounded to a fine powder and placed in a previously warmed plumbago crucible about 8 inches by 7 inches, then stirred with a wooden spoon for a minute or two. The acid is then added with about 1 ounce of boiling water, and the mass constantly stirred until it boils up to the top of the pot. The work, which has been previously cleansed in hot potash or soda solution, is then suspended in the colouring liquid by means of a silver or platinum wire for about one minute, then well swilled in boiling water. A little more water is added to the colour-pot, and when the liquid boils up the work is again immersed for another minute, and swilled in boiling water as before. This operation of dipping and swilling is repeated several times, the colouring liquid being weakened by adding water before each immersion, until the desired appearance is attained. The work is finally well washed in hot water and dried in boxwood saw-dust. The whole process takes five to seven minutes.

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[1] *Goldsmiths' Handbook*, p. 161.

The coloured work is next scratch-brushed, on a lathe, with a revolving brush made of very fine brass wire and having stale beer dropping on it. If the colouring has been properly conducted, a beautiful rich and dead colour will be produced.

Dry Colouring.—This term is applied to the colouring process when no liquids are used as constituents of the mixture. The ingredients used are—

Potassium nitrate . . .	8 ounces
Common salt	4 ,,
Alum	4 ,,

These substances are ground to a fine powder, well mixed and placed in a previously heated blacklead "colour"-pot, of the same dimensions as that described for use in wet colouring, but the same pot must not be employed for dry colouring as has been used for the wet process. It is well to get the pot nearly red-hot before placing the "colour" in it. The mixture must then be constantly stirred with an iron rod. It will first boil up as a greenish liquid, then solidify, and afterwards boil up a second time and become thoroughly fused, having a brownish-yellow colour. At this stage the work, which has been previously annealed and dipped in dilute aquafortis, is dipped in the "colour," being suspended on a silver or platinum wire, the latter being preferred, and kept in motion for about a minute and half, then immersed in boiling water containing a little aquafortis. The immersion and swilling are again repeated, when the articles possess a beautiful colour. They are then washed in hot water containing a little potash, and finally dried in warm boxwood saw-dust.

In dry-colouring the work should be as highly polished as possible previous to the colouring, for the brighter it is the better will be the final colour. The time given above is only intended as a general guide, as some work will colour much quicker than others, and the time can only be arrived at by experience. The following mixtures have been recommended for colouring :—

Dry process.	
Potassium nitrate	8 oz.
Common salt	4 ,,
Alum	4 ,,
Sal-ammoniac	4 oz.
Potassium nitrate	4 ,,
Borax	4 ,,

Wet process.				
Potassium nitrate	8	14	15	14
Common salt	4	7	7	7
Alum	4	7	7	...
Hydrochloric acid	...	2	1	5
Water in each case	...	...	...	...

The following is a useful mixture for removing tarnish from coloured-gold articles which have been kept in stock for some time :—

Bicarbonate of soda	2 ounces
Chloride of lime	1 ,,
Common salt	1 ,,
Water	16 ,,

Well mix the above ingredients and apply with a soft brush.

CHAPTER X

SILVER ALLOYS

§ 148. Articles are very seldom manufactured from fine silver free from alloy, as pure silver is far too soft to resist the wear to which most bodies are subjected. It is therefore alloyed with some other metal, chiefly copper, to impart the requisite degree of hardness. Fine silver, in consequence of its high ductility, is used in the manufacture of silver lace and fine filigree-work, the latter being principally made in India, Sweden, Norway, and some parts of Germany, where labour is cheap.

The purest commercial silver contains minute quantities of other elements, which, in the best varieties, do not materially affect its working properties. It may be necessary in some cases to obtain chemically pure silver, and this may be done in the following ways. Ordinary silver is dissolved in pure nitric acid, when any gold is left undissolved, and is removed by filtration. The silver solution is next evaporated to dryness, and the residue fused to decompose any platinum nitrate that may be present. The residue is then dissolved in dilute ammonia and filtered; and the filtered blue liquid diluted with enough water to bring the strength down to 2 per cent of silver. A sufficient quantity of normal ammonium sulphate is now added to render the solution colourless on warming, and the liquid is allowed to stand in closed stoppered vessels for twenty-four hours, when a third of the silver separates out in the crystalline form.

The liquid, which is still blue when cold, is poured off and heated from 60° to 70° C., when the remainder of the silver is deposited. In order to remove every trace of copper, the metallic precipitate is washed with water, and allowed to stand several days in contact with strong ammonia; it is then again washed, dried, and fused in an unglazed porcelain crucible with 5 per cent of pure borax and 5 per cent of pure sodium nitrate. Lastly, it is cast in moulds lined with a mixture of burnt and unburnt porcelain clay. The bars of silver must then be cleaned with sand, and heated with potash solution to remove every trace of adherent silicate, and finally washed with water.

To prepare pure silver, Stas dissolved fine silver in dilute nitric acid, evaporated the solution to dryness, and ignited the residue until all the red fumes were evolved. The mass was dissolved in water, filtered, and diluted with rain-water (30 of water to 1 of silver) and the silver precipitated as chloride with pure hydrochloric acid. The precipitate was washed with dilute hydrochloric acid, then with pure water, and then dried, and the powder well rubbed in a clean porcelain mortar. This was then repeatedly digested with aqua-regia, and afterwards well washed. The silver chloride was then reduced to metal by boiling with dilute pure caustic potash and some milk-sugar. The reduced silver was washed with dilute sulphuric acid, then with water, then dried and fused.

Metallic silver has the power of absorbing certain gases when melted in contact with them, but the gases are, for the most part, expelled during the solidification of the metal, raising blisters on the surface, or covering the same with a number of small excrescences, giving it a frosted appearance. This action is termed *spitting* or *vegetating*. When molten silver is allowed to cool slowly out of contact with air, the gases gradually escape, and little evidence of spitting is exhibited. The gas which produces this phenomenon is principally oxygen. When silver is melted under a sufficiently thick layer of non-oxidising material, such as common salt, or potash, the metal solidifies with a bright surface, showing that oxygen had not been absorbed and afterwards emitted. When powdered charcoal is thrown on the surface of the metal, the carbon withdraws the absorbed oxygen and prevents the silver from spitting.

Silver may be alloyed with gold, even to the extent of one-third of its weight, without losing its power of absorbing oxygen when melted, and of spitting during solidification. [1] Chevillot states that silver alloyed with copper, of the respective standards 990 and 995 parts of silver per 1000, exhibit the phenomenon of spitting; that silver of the standard 952 does not evolve gas in sensible quantity; and he supposes that silver of the standard 980 is the limit at which spitting occurs.

Silver is capable of absorbing oxygen and other gases, and retaining them when cold, by heating the metal to redness in contact with oxygen or other gas. Such gas is said to be *occluded.* Graham found that pure silver occluded ·545 of its volume of oxygen; and fine silver wire ·002 inch diameter, yielded ·289 of its volume of a gas, consisting chiefly of carbonic acid. When standard silver is heated to low-redness it becomes almost black on the surface, from the oxidation of the copper. Silver wire thus blackened was found to have occluded several times its volume of oxygen. Fine silver wire heated to redness in hydrogen, and cooled in that gas, occludes ·211 of its volume of hydrogen.

Fine silver is somewhat extensively used in the manufacture of fine wire and filigree-work on the Continent and in India. The Indian workman accomplishes work of a very beautiful kind, representing flowers, animals, etc., with true artistic taste. The articles are "hand-made" with the aid of a few simple tools. The work is commenced by hammering out the metal on an anvil, and when it has assumed a certain degree of thinness, it is cut into strips, and drawn into very thin wire through perforated steel plates, a pair of strong pliers being used for the purpose. The wire is then used for fashioning various ornamental articles. Indian filigree-work is said to be the finest and cheapest in the world. It is of importance, in this class of work, that the various forms required in filigree-work should steadily retain their place when pressed into shape, and not rebound like metals of a highly elastic nature, hence the need of using fine silver in preference to standard silver.

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[1] *Memoirs of the Phil. Soc. of Manchester*, second series, 1819, p. 271.

§ 149. **Silver and Arsenic.**—These metals are capable of uniting in several proportions, forming hard, gray, brittle, and readily fusible alloys. Gehlen produced an alloy containing 16 per cent arsenic, which is compact, brittle, steel-gray, and fine-grained. Berthier describes an alloy of 14·8 per cent arsenic as dull-gray, brittle, and crystalline; by burnishing it acquires the lustre and colour of silver; it is very fusible, and not decomposed on heating. Guettier describes an alloy containing 14 per cent arsenic, formerly used for table ware. Mr. R. Smith prepared a hard and brittle though somewhat tough alloy, which became white and lustrous on burnishing. It contained 18·54 per cent arsenic, and corresponded to the formula Ag_3As.

Silver-arsenic alloys may be prepared by direct fusion of the constituent metals, or by melting a mixture of silver, arsenious acid, and black flux.

§ 150. **Silver and Antimony.**—Alloys of these metals may be obtained in all proportions by direct fusion. They are hard, brittle, and gray or white in colour. The whiteness decreases with the proportion of antimony. The alloys are very fusible, and wholly decomposed by cupellation or by fusion with nitre, pure silver remaining. [1] Mr. R. Smith has prepared the following alloys:—

	I	II	III
Silver . .	72·65	77·98	84·16
Antimony .	27·35	22·02	15·84

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[1] Percy's *Gold and Silver*, vol. i. p. 143.

—corresponding to the formulæ $3Ag + Sb$, $4Ag + Sb$, and $6Ag + Sb$ respectively. The silver was melted first under a layer of charcoal, and the antimony then added. No. I was hard, crystalline, and bluish-white. No. II was similar to No. I, but grayish-white. No. III was hard, granular, and grayish-white. The specific gravities of 48 silver-antimony alloys containing 50 per cent of silver, and upwards, has been determined by Cooke, of Harvard College, U.S., who found that the densities were above the mean densities of the constituents, the maximum being reached in the alloy containing 26·6 per cent of antimony. Cooke also found that the crystallisation of the alloys becomes marked in proportion as the same composition is approached.

§ 151. **Silver and Bismuth.**—Alloys of these metals are hard, easily fusible, brittle, and lamellar in structure. The colour of the 50 per cent silver alloy is the same as that of bismuth. An alloy containing 33·33 per cent silver is said to be steel-gray and to expand on solidification. Schneider states that when impure bismuth, containing sulphur, arsenic, iron, nickel, and silver, is fused and poured upon a cold plate, the globules of metal which are thrown up during solidification of the mass contain at least 99·5 per cent bismuth, and of the heavy metals only silver is found in the bismuth.

§ 152. **Silver and Tin.**—The smallest quantity of tin renders silver brittle. Alloys of tin and silver, according to Guettier, are harsh, very hard, and brittle. An alloy of 80 per cent tin is nearly as hard as bronze. An alloy of 52 per cent tin is somewhat malleable. These alloys are very easily oxidised. They have a specific gravity less than the mean of the constituents. Tin may be removed from silver by fusion with bichloride of mercury (corrosive sublimate), leaving the silver pure. Dentists use an alloy of 60 parts silver and 40 parts tin, in admixture with mercury, for stopping teeth.

§ 153. **Silver and Zinc.**—These metals combine very readily, forming bluish-gray and, for the most part, brittle alloys. Those with excess of zinc are granular, but with an excess of silver the fracture becomes columnar. The metals combine much more readily at a high than at a moderate temperature. [1] Berthier prepared an alloy containing 80 per cent silver, which he states was rolled into very thin leaf; it was rigid, elastic, very tenacious, and tough.

[2] Mr. G. H. Godfrey prepared the following alloys by pouring molten zinc into molten silver;—

	I	II	III	IV
Silver	8·16	22·47	49·72	67·58
Zinc	91·84	77·53	50·28	32·42

"I. The surface was bluish-gray. The metal was hard, easily frangible, and easily scratched with a knife. Its fracture was bluish-gray, finely granular, and feebly lustrous.

"II. The surface was bluish-gray. The metal was harder than No. I, easily frangible, but less easily scratched. Its fracture was bluish-gray, bright, and fibro-columnar.

"III. The surface was copper-red after solidification. The metal was hard, brittle, and easily pulverised. The broken surface, when fractured cold, was white and very bright, and somewhat columnar.

"IV. The surface had a faint reddish-yellow tint. The metal was hard and easily frangible; its fracture white and very bright, but it soon tarnished; it was columnar in structure."

An alloy of 2 parts by weight of zinc and 1 part silver is said to be ductile, finely granular, and nearly as white as silver.[3]

Silver-zinc alloys have been proposed for coinage purposes. Peligot prepared alloys containing 5, 10, and 20 per cent of zinc respectively. They were white, with a tinge of yellow. The coins were elastic and sonorous. These alloys are not so readily blackened by sulphuretted hydrogen as silver-copper alloys.

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[1] *Traité des Ess.* (2) p. 798.

[2] Percy's *Gold and Silver*, vol. i. p. 169.

[3] *Handwörterbuch der Chemie* (7), p. 958

§ 154. **Silver and Iron.**—These metals do not alloy well together. Messrs. Stoddard and Faraday made some experiments with silver in steel, and concluded that $\frac{1}{300}$ of silver corresponds to the best mixture. These alloys do not appear to present any practical interest.

§ 155. **Silver and Nickel.**—Berthier described an alloy of these metals containing 13·5 per cent nickel which was white, and capable of a high polish; it rolled well, and was very tough. There appears to be very little known concerning alloys of these two metals alone.

§ 156. **Silver and Lead.**—Alloys of these metals are of little interest from a commercial point of view. The metals readily unite in all proportions. A very small amount of lead is sufficient to diminish the malleability and ductility of silver. Molten lead dissolves silver just as mercury does, and homogeneous mixtures are obtained only while the metals are liquid, a certain amount of liquation taking place as the metals cool. [1] Levol has investigated this subject, and his results are tabulated below.

	Atomic formula.	Silver per 1000 of alloy.		Variations in the ingot.
		Calculated.	Found.	
I	$Ag_{20}Pb$	912·5	914	7·5
II	$Ag_{12}Pb$	862·0	863	14·5
III	$Ag_{10}Pb$	839·1	840·5	23·5
IV	$Ag_4 Pb$	675·9	676·5	49·5
V	$Ag_2 Pb$	510·5	516·6	66·5
VI	$Ag Pb$	342·8	347·5	11·0
VII	$Ag_2 Pb_3$	258·0	262·0	13·0
VIII	$Ag Pb_2$	206·8	206·0	6·5
IX	$Ag Pb_5$	94·4	...	19·5
X	$Ag_2 Pb_{15}$	65·0	67·25	7·5
XI	$Ag Pb_{10}$	49·4	46·00	2·5
XII	$Ag Pb_{50}$	10·3	9·75	·25

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[1] *Mémoire sur les Alliages, Ann. de Chim.* 1853, 3, ser. 39, p. 173.

I. Grayish-white, but little malleable, and contracts during solidification.

II. Grayish-white, resembles platinum in colour and grain, contracts during solidification, and changes rapidly in moist air.

III. Grayish-white; contracts strongly during solidification; heated in air it assumes a beautiful violet-blue tint.

IV. Alloy tolerably malleable, but has only feeble tenacity, and melts near cherry-red heat; it is bluish-gray in colour, and quickly oxidises in moist air.

V. [1] Is much more like lead than silver, soft, and tolerably malleable and ductile.

The others require no special comments.

§ 157. **Silver and Aluminium.**—Alloys of these metals were made some years ago, and it was thought that valuable metals of a white colour, and unaffected by the atmosphere, would be obtained, which would make them superior to ordinary silver-copper alloys, but these great expectations have not as yet been realised. Aluminium hardens silver, and the alloys admit of a high polish.

[2] MM. C. and A. Tissier state that an alloy of 4·75 per cent silver and 95·25 aluminium is more elastic and harder than aluminium, and as malleable as the latter metal. Aluminium alloyed with 10 per cent silver is no longer malleable. An alloy of equal parts of silver and aluminium is said to be as hard as bronze. [3] Lange uses an alloy of 100 parts aluminium and 5 parts silver for watch-springs. Such springs are said to be very elastic, hard, light, not so brittle as steel, and not to rust.

Tiers-argent (one-third silver).—This alloy is said to be manufactured at Paris into various utensils, and consists of 33·33 parts silver and 66·66 parts aluminium. MM. Tissier state that this same alloy may be used as a solder, but it runs with difficulty and produces a brittle joint.

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[1] Guettier, *Guide Pratique des Alliages*, 1865, p. 150.

[2] *L'Aluminium et les Métaux alkalius*, 1858, p. 173.

[3] *Jahresber.* 1874, p. 1077.

§ 158. **Silver and Copper.**—These metals unite in all proportions, forming a series of most valuable alloys, having a great variety of applications in the Arts. Combination takes place with expansion, so that the specific gravities are less than the mean of their constituents. Most of the alloys are as ductile as silver, and possess more hardness, elasticity, and sonorousness. The colour of these alloys is white until the copper reaches nearly 50 per cent, and beyond that the colour is yellowish, up to about 70 per cent copper, when a red tint prevails. The hardest alloy is that containing 5 parts by weight of silver to 10 or 11 parts copper.

[1] Professor Roberts-Austen has determined the melting points of certain silver-copper alloys, and states that the alloy containing 630·29 of silver per 1000 of alloy, and represented by the formula AgCu, has a lower melting point than silver, or than any other alloy of silver and copper. His results are given in the following table. He has since communicated to the author the fact that the results are too high, as more recent determinations of the melting point of silver make it 940° C. instead of 1040° C. According to J. Violle its melting point is 954° C.[2]

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[1] *Pro. Roy. Soc.* vol. xxiii. pp. 349, 481.

[2] *Compt. rend.* tom. lxxxv. p. 543.

No.	Pure silver per 1000.	Approximate formula.	Melting point.
1	1000	Ag	1040° C.
2	925	Ag_7Cu	931·1° C.
3	820·7	Ag_3Cu	886·2° ,,
4	798	Ag_5Cu_2	887° ,,
5	773·6	Ag_2Cu	858·3° ,,
6	750·3	Ag_7Cu_4	850·4° ,,
7	718·93	Ag_3Cu_2	870·5° ,,
8	630·29	$AgCu$	846·8° ,,
9	600	Ag_7Cu_8	857° ,,
10	569·9	Ag_7Cu_9	899·9° ,,
11	561·1	Ag_3Cu_4	917·6° ,,
12	540·8	$Ag_{20}Cu_{29}$	919·8° ,,
13	500	Ag_3Cu_5	940·8° ,,
14	497	$Ag_{25}Cu_{43}$	962·6° ,,
15	459·4	$AgCu_2$	960·8° ,,
16	250·5	$AgCu_5$	1114·1° ,,
17	Pure copper	Cu	1330° ,,

The alloys numbered 7 and 8 are of especial interest. The first Ag_3Cu_2 is Levol's homogeneous alloy, which remains uniform in composition, while many others undergo liquation on slow cooling. The alloy AgCu has the simplest atomic relation and the lowest melting point.

In studying the phenomena of liquation, the alloys were cast in moulds of fire-brick, in which the metal (about 50 ounces) could be quickly or slowly and uniformly cooled. The results showed that the homogeneity of Levol's alloy is slightly disturbed by this method of casting; and, on the other hand, that alloys which contain more than 71·89 per cent of silver hardly show signs of rearrangement when the solidification takes place gradually. Two alloys containing 63 and 33·3 per cent of silver respectively, were found to be far from homogeneous, and in the former the arrangement was influenced by gravity, the base of the casting being richer in silver. The following table contains a summary of Roberts-Austen's results :—

No.	Designation.	Parts of silver per 1000.	Rate of cooling.	Maximum variation in the quantity of silver in different parts of the alloy.
I a	British standard coins	925	rapid	12·8 per 1000
I b			slow	1·4 ,, ,,
II a	Old French standard coin	900	rapid	10·1 ,, ,,
II b			slow	1·3 ,, ,,
III	Levol's homogeneous alloy	718·93	slow	1·2 ,, ,,
IV	AgCu	630·3	slow	21·1 ,, ,,
V	$AgCu_4$	333·3	slow	12·8 ,, ,,

In I a and II a the centre of the cubes was the richest and the corners the poorest.

In I b and II b the slight variations followed the same law.

In III the corners were generally richer than the centre.

In IV it was supposed that gravity had influenced the alloy, the lower parts being richer than the upper.

In V the variations do not follow any known law.

With regard to standard silver cast under ordinary conditions, the tendency of the copper and silver to separate appears to depend upon the inequality of the rate of cooling in the different parts of the ingot. The act of cooling causes a partial separation of the copper at the parts first cooled, and those parts which solidify last are generally richer in silver.

Silver-copper alloys are subject to change when strongly heated in air, the copper being oxidised. If the alloy contains much copper, the silver will also, to some extent, be oxidised, but in a less degree than the copper. When such alloys are just heated to redness in an ordinary muffle with accession of air the discoloration of the surface is proportionate to the amount of copper. The following table is due to Chaudet[1]:—

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[1] *L'Art de l'Essayeur.* Par M. Chaudet, pp. 77, 78.

Silver in 1000 parts of alloy.	Characters of the surfaces after heating.
1000, *i.e.* pure silver	Dull but white.
950	Uniform gray-white.
900	Dull gray-white, black fillet at edges.
880	Gray, almost black.
860	,, ,,
840	Quite black.
820	,, ,,
800	,, ,,

§ 159. *Standard or Sterling Silver.*—British silver coin and plate contain definite proportions of silver and copper, regulated by law. Silver coin contains 11 oz. 2 dwts. of silver per lb. troy, or 925 parts of silver per 1000, the remaining 75 parts being copper. It should be mentioned that the copper, added to the silver, is termed the alloy, whereas, strictly speaking, the whole body, containing silver and copper, is the alloy. Articles of silver to be Hall-marked must be made of standard silver, as no other quality is allowed by law to be assay-marked.

In preparing standard silver for Hall-marking it is necessary to add a little more than the above stated amount, because commercial fine silver is never perfectly pure; so that instead of using 18 dwts. 12 grs. per ounce, use 18 dwts. 14 grs. The quality commonly used by silversmiths is generally below the standard, when not Hall-marked, and contains 18 dwts. of silver per ounce, or 900 parts per 1000.

§ 160. The various alloys of silver and copper employed for manufacturing purposes are represented in the following table[1] :—

	I	II	III	IV
	oz. dwt. gr.	oz. dwt. gr.	oz. dwt. gr.	oz. dwt. gr.
Silver	0 18 0	0 16 0	0 15 0	0 14 0
Copper	0 2 0	0 4 0	0 5 0	0 6 0

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[1] Gee, *Silversmiths' Handbook*, pp. 64-67.

	V	VI	VII	VIII
	oz. dwt. gr.	oz. dwt. gr.	oz. dwt. gr.	oz. dwt. gr.
Silver . .	0 13 12	0 13 0	0 12 12	0 12 0
Copper . .	0 6 12	0 7 0	0 7 12	0 8 0

No. VIII is about the commonest alloy it is possible to make without a perceptible yellow cast being imparted to the colour. A commoner variety may, however, be made by adding a third metal such as nickel, which will be subsequently referred to.

The alloys for coin and plate until recently legal in France were as follows[1]:—

	Specific gravity.	Copper in 1000 parts.	Errors tolerated. Copper in 1000 parts.
Silver coin . . .	10·26 to 10·3	100	97 to 103
Coin named "billon" .	9·37 to 9·5	800	797 to 807
Silver plate . . .	...	50	50 to 55
,, medals . . .	...	50	47 to 53
,, jewellery . .	...	200	...
,, solder . . .	...	120 to 330	...

The 10 centimes pieces, termed "billon," have not been made since 1810. The standard for all French silver coins under the 5-franc piece has been lowered to 835 of silver per 1000 of alloy.

In Germany there are four silver standards, which are as follows:—

Silver ware .	11 oz.	8 dwts.	or 950 parts silver per 1000
Coinage . .	10 ,,	16 ,,	or 900 ,, ,, ,,
Silver ware .	9 ,,	12 ,,	or 800 ,, ,, ,,
Silver ware .	9 ,,	0 ,,	or 750 ,, ,, ,,

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[1] *L'Art de l'Essayeur.* Par M. Chaudet, p. 335.

No other metal than copper is allowed to be alloyed with the silver.

Elliot and Storer[1] have detected the presence of lead in silver coins of the United States and other countries. Their results are given in the following table :—

Kind of coin.	Silver per 1000.	Lead per cent.
1 American half-dollar, 1824 . . .	900	·3100
20 ,, 5-cent pieces, 1853 . . .	900	·2090
10 ,, ,, ,, 1854 . . .	900	·2282
2 ,, 25-cent ,, 1858 . . .	900	·2305
Fine silver from U.S. Assay Office in New York, 1860	...	·1611
1 Spanish dollar, 1793, Carolus IV . .	...	·0558
1 Mexican ,, 1829	...	·0434
2 English shillings, 1816	925	·4847
1 French 5-franc piece, 1852, Napoleon III	900	·4282

The lead in American coins is accounted for by the zinc, used in the reduction of the chloride of silver, containing some lead. The silver at the French Mint is precipitated by copper from an acid solution of sulphate of silver, and the acid probably contains sulphate of lead. The lead in English coin may be due to imperfect cupellation.

The following table gives the composition of coins of various countries :—

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[1] *Amer. Acad. of Arts and Sc.* 1860, p. 52.

Country.	Coins.	Fineness.
Great Britain	Shilling, etc.	925
Australasia	,,	,,
Cape of Good Hope	,,	,,
Canada	50 cents	,,
Newfoundland	,,	,,
East Indies, Burmah, Ceylon, and Mauritius	Rupee	916·667
[1] France, Belgium, and Switzerland	5 Francs	900
Italy	5 Liras	,,
Greece	5 Drachms	,,
Servia	5 Dinars	,,
Roumania	5 Leys	,,
Bulgaria	21 Lew	835
Austria, Hungary	Florins	900
Spain	5 Pesedas, 2 escudos	,,
Argentine Republic	1 Peso	,,
Bolivia	1 Boliviano	,,
Chili	1 Peso	,,
Peru	1 Sol	,,
Germany	1 Mark	,,
Russia	1 Rouble	868·056
Denmark, Sweden, and Norway	2 Crowns	800
Netherlands	1 Florin	945
Portugal	5 Testoons	916·667
Ottoman Empire	20 Piastres	830
Egypt	10 Piastres	900
Persia	10 Scahis	,,
United States	1 Dollar	,,
Mexico	1 Peso	902·778
Brazil	2 Milreis	916·667
Japan	1 Yen	900
Cochin China	Trade piastre	,,

Silver, Copper, Zinc, and Nickel.—Some foreign coins have been made of alloys of these metals; and certain French manufacturers have employed alloys of copper, nickel, and silver as a substitute for standard silver.

A series of alloys known as *Argent-Ruolz* were patented by De Ruolz and De Fontenay in 1853, which they state may be used for all purposes for which silver is usually employed.

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[1] See p. 328.

The alloys contain 20 parts silver, 30 to 75 parts nickel, and 70 to 75 parts copper. It is recommended to melt the copper and nickel first, and then to add the silver. Charcoal and borax are to be used as the flux, and the ingots obtained are to be rendered malleable by heating them for some time in powdered charcoal. A second patent was obtained in 1854 for the introduction of a little phosphorus into the same alloys. The advantages claimed are:—that the alloys are more fusible, the molten metal very liquid, and the castings free from porosity, closer in grain, and whiter in colour. The phosphorus, however, greatly lessens the malleability and ductility of the alloys.

C. D. Abel of London also patented certain silver alloys containing nickel, having the following composition:—

	I	II	III
Silver . . .	33	40	20
Nickel . . .	25 to 30	20 to 30	25 to 35
Copper . . .	37 to 42	30 to 40	45 to 55

	IV	V	VI
Silver . . .	33·3	34	40
Nickel . . .	8·6	8	4·6
Copper . . .	41·8	42	44·6
Zinc . . .	16·3	16	10·8

Nos. IV and V are specially designed for rolled, pressed, or drawn silver work; No. III for cast work; and No. VI for jewellery.

Mousset's silver alloy contains 59½ copper, 27½ silver, 9½ zinc, and 3½ nickel per cent.

Swiss monetary alloys are composed of :—

	20 Centimes.	10 Centimes.	5 Centimes.
Silver . . .	15	10	5
Copper . . .	50	55	60
Nickel . . .	25	25	25
Zinc . . .	10	10	10

Mr. A. Parkes of Birmingham patented in 1844 the following alloys :—

	I	II
Silver	20	10
Nickel	20	10
Copper	60	60
Zinc	...	20
	100	100

[1] Peligot prepared the following alloys, which are said to be whiter and more malleable than alloys of silver and copper containing the same proportions of silver :—

	I	II	III
Silver . .	90	80	83·5
Copper . .	5	10	9·3
Zinc . . .	5	10	7·2

The following alloys have been compiled from various sources :—

	I	II	III	IV	V	V	VII	VIII	IX
Silver . .	40	36·4	31	27	25	20	40	36	33
Copper . .	33	36·4	40	42	44	50	32	34	37
Nickel . .	26	27·2	29	31	31	30	21	22	25
Zinc . .	...	...	...	...	...	...	7	8	5

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[1] *Comptes rendus*, 1864, p. 645.

Silver, Copper, and Cadmium.—Brannt states that cadmium imparts to silver alloys great flexibility and ductility without impairing their white colour, and gives the following as the more important alloys :—

	I	II	III	IV	V	VI	VII
Silver . .	980	950	900	800	666	667	500
Copper .	15	15	18	20	25	50	50
Cadmium .	5	35	82	180	309	284	450

SILVER SOLDERS

§ 161. A solder must be more fusible than the articles to be soldered, should run well when fused, and blend perfectly with the edges or surfaces to be united, otherwise strong and invisible connections cannot be effected; hence solders of different qualities are required for different proportions of the metals in the alloys. The best junctions are made when the metal and solder are, as nearly as possible, equal as regards hardness, malleability, and fusibility. When the fusibility of the solder is nearly the same as that of the metal, greater skill is required on the part of the workman to prevent the metal melting, but the union will be more perfect. As a metal approaches its melting-point it becomes more and more expanded, *i.e.* more porous in structure, and the molecules of the solder, when melted, will more easily penetrate the meshes of the molecular network of the metal, and form a more intimate relationship.

[1] Gee says, "the best solders we have found to be those mixed with a little zinc. These may be laminated, rolled, or filed into dust; if the latter, it should be finely done, and this is better for every purpose. Too much zinc has a tendency to eat itself away during wear, thus destroying the article

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[1] *Silversmiths' Handbook*, p. 76.

after a certain time. Such solders also volatilise considerably during soldering, so that the soldering operation has often to be repeated, thus wasting time and solder." The hardest solders, *i.e.* those most difficult to melt, are those made of silver and copper only; medium solders contain zinc in addition to copper and silver; and the easiest or softest solders are prepared with the addition of a certain proportion of tin. Arsenic is sometimes added to produce greater fusibility.

For two metal surfaces to be joined together by soldering it is necessary that they should be clean. But during heating oxidation takes place, unless the metal is protected from the oxygen of the air, so that a flux is added with a view of protection, and also for the purpose of dissolving the oxide formed, and leaving the parts to be joined perfectly clean. The flux used for the above purpose is borax.

English Silver Solders.

[1] I. Fine silver 4 parts by weight, copper 1 part.

II. Standard silver 3 parts by weight, brass (2 copper, to 1 zinc) 1 part.

III. Fine silver 2 parts by weight, brass 1 part.

Mr. Edward Matthey states that No. III is a very nice white solder and is used for ordinary plate-work. Gee says that the above solders are not the best for ordinary silver work. The first is too difficult to melt. The second and third are liable to contain lead, which burns away and corrodes the metal. The same remarks apply to No. III. When brass is used in making solder care must be taken that the spelter used in its composition is free from lead.

In order to test the suitability of different compositions for soldering articles made of standard silver, the author performed the following experiments. A sample of solder, used for this purpose, was obtained from a large manufacturer, and on analysis gave :—

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[1] Percy's *Gold and Silver*, p. 166.

Silver . . .	64·15
Copper . . .	22·85
Zinc . . .	13·00
	100

As the goods manufactured by the above firm require to be Hall-marked, it is necessary to make the metal better than standard in order to compensate for the low standard of the solder. The object of the author was, therefore, to obtain a solder as near as possible to standard silver, and thus avoid the necessity of alloying the metal so high. It was thought that by reducing the quantity of copper and replacing it by zinc the object might be attained.

	I	II	III	IV
Silver	925	925	925	925
Copper	50	38	25	...
Zinc	25	37	50	75

The above solders were tested by an experienced workman and all pronounced too hard, and not sufficiently liquid when melted to run well. No. II was considered the best of the series. The following were then tried:—

	I	II	III
Silver	800	800	800
Copper	100	50	25
Zinc	100	150	175

No. I was found to be the hardest, and No. III the easiest to melt, which ran as readily as the solder given in the above analysis, containing 64 per cent of silver, and appeared to answer the purpose equally well.

The following solder is mentioned by Tenner as suitable for jewellery:—

	Parts by weight.		oz.	dwt.	gr.
Silver . . .	63·3	or	0	12	16
Copper . . .	3·4	,,	0	0	16
Brass . . .	33·3	,,	0	6	16
	100		1	0	0

French Silver Solders.—The following solder is used for soldering silver wares of the standard 950 :—

	Parts by weight.
Silver . . .	66·6
Copper . .	23·3
Zinc . . .	10
	99·9

In making this solder, it is recommended to previously alloy the zinc with twice its weight of copper, when the following proportions are used :—

Silver . . .	66·6
Brass . . .	30
Copper . . .	3·3
	99·9

[1]Guettier gives the following :—

	I	II	III	IV	V	VI
Silver	5	3	2	4	2	1
Brass	1	1	1	...	...	...
Bronze (90 copper, 10 tin)	...	...	...	3	...	1
Arsenic . . - .	...	...	...	·25	·5	...
Copper	...	...	...	...	1	1

He further states that these solders ought to be melted several times. The metal is then laminated into thin bands, which are granulated into spangles, ready to be mixed with borax. When arsenic is used, it is not added until after the fusion of the other metals.

Gee denies that there is any advantage in remelting silver solder containing zinc several times, but that his experience is in direct opposition to this practice. Solders, into the composition of which volatile metals enter, become hard, brittle, and "drossy" by repeated remeltings, and are best only melted once. In 1635 Bate published the following directions for preparing silver solders. "Take a quarter of an ounce of silver and 3 pennyweights of copper, melt them together, and it is done."

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[1] *Guide Pratique des Alliages Métalliques*, pp. 324, 326.

[1] The following solders are recommended for special work:—

		oz.	dwt.	gr.			oz.	dwt.	gr.
I.	Fine silver	1	0	0	II.	Fine silver	1	0	0
	Shot copper	0	5	0		Shot copper	0	10	0
		1	5	0			1	10	0

		oz.	dwt.	gr.			oz.	dwt.	gr.
III.	Fine silver	0	16	0	IV.	Fine silver	1	0	0
	Shot copper	0	0	12		Composition	0	10	0
	Composition	0	3	12		Pure tin	0	2	0
		1	0	0			1	12	0

		oz.	dwt.	gr.			oz.	dwt.	gr.
V.	Fine silver	1	0	0	VI.	Fine silver	1	0	0
	Shot copper	0	12	0		Shot copper	0	3	0
	Pure spelter	0	3	0		Arsenic	0	2	0
		1	15	0			1	5	0

		oz.	dwt.	gr.			oz.	dwt.	gr.
VII.	Fine silver	1	0	0	VIII.	Fine silver	1	0	0
	Composition	0	6	0		Composition	0	5	0
	Arsenic	0	1	0		Tin	0	5	0
		1	7	0			1	10	0

		oz.	dwt.	gr.			oz.	dwt.	gr.
IX.	Fine silver	1	0	0	X.	Fine silver	1	0	0
	Tin	0	10	0		Composition	0	15	0
	Arsenic	0	5	0		Arsenic	0	1	6
		1	15	0			1	16	6

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[1] Gee's *Silversmiths' Handbook*, p. 84.

Nos. I and II are recommended for work to be enamelled. No. III. Easy solder for filigree-work. No. IV. Easy solder for chains. No. V. Common easy solder. No. VIII. Easy silver solder. Nos. IX and X. Common easy solders.

Silver solders are used for soldering other metals and alloys, such as cast-iron, steel, brass, German silver, gold alloys, etc.

As already mentioned, the substance most commonly used as a flux in hard-soldering is borax. Powdered glass is occasionally used with very hard solders. In Vienna a substance is used termed "streu-borax," or "sprinkle-borax." It is composed of the following ingredients, which should be gently heated to expel the water of crystallisation, and the whole well pounded ready for use:—

	Parts by weight.
Calcined borax	87½
Carbonate of soda . . .	7½
Common salt	5
	100

The object of the mixture is to prevent the rising of the solder, and to facilitate its flushing. It, however, encumbers the work with more flux than when borax alone is used, and, if kept for some time after mixing in the wet state, turns the solder yellow.

IMITATION SILVER ALLOYS

§ 162. *Clark's Patent Alloy.*—Copper 75, nickel 14·5, zinc 7·5, tin 1·5, cobalt 1·5 per cent.

Baudoin's Alloy.—Copper 72, nickel 16·6, cobalt 1·8, tin 2·5, zinc 7·1 per cent. About ½ per cent of aluminium may also be added.

Parisian Alloy.—Copper 69, nickel 19·5, zinc 6·5, cadmium 5 per cent.

White Alloy.—Copper 64·5, tin 32, arsenic 3·5 per cent.

Chinese Silver.—Copper 58, zinc 17·5, nickel 11·5, cobalt 11, silver 2 per cent.

Warne's Alloy.—Tin 37, nickel 26, bismuth 26, cobalt 11 per cent.

Minargent.—Copper 56, nickel 40, tungsten 3, aluminium 1 per cent.

White Alloy.—Copper 59, tin 31, brass 8, arsenic 2 per cent.

See also the chapter on German silvers, and also the alloys of silver, zinc, copper, and nickel.

The above alloys are used for cheap jewellery and electroplated wares. Wires prepared from them may serve for stems of pins, brooch tongs, catches and joints, etc. They are harder and more difficult to work than ordinary silver alloys, but their hardness and tenacity adapt them for the purposes above mentioned.

MIXING AND MELTING OF SILVER AND ITS ALLOYS

§ 163.—The crucibles best adapted for melting silver are made of clay and plumbago and known as "blacklead" and plumbago crucibles. They are capable of withstanding the action of heat and sudden changes of temperature much better than ordinary clay crucibles, and if previously annealed, can be used many times in succession without cracking or breaking. They also resist the corrosive action of slags and fluxes better than clay-pots.

Alloys consisting of silver and copper only, may be prepared by melting the two metals together, as previously stated, under a layer of charcoal powder. When melted the mixture should be well stirred with an iron rod, and the metal, if at the proper temperature, poured. When zinc is a constituent of the alloy, that metal must be heated and cautiously added after the silver and copper are melted, and the whole then vigorously stirred. It should be borne in mind that zinc is a volatile metal, and that the volatility increases as the temperature rises, so that it is advisable to add the zinc as soon as the other metals are melted. The metal is generally poured into flat ingot-moulds, so as to produce a plate of silver suitable for rolling and for wire-drawing, and the same precautions apply as stated when treating of gold alloys. The charcoal powder employed should be of good quality, as defective alloys are sometimes produced by using bad charcoal. When tin is used, it should be added after melting the silver and copper, but this is not so necessary as in the case of zinc or arsenic.

When scrap silver or silver alloys are added to the crucible alone, or along with new metal, certain impurities may also be admitted, and a flux will be necessary to remove them. In most cases carbonate of soda or borax is employed. The latter should be sparingly used.

§ 164. *Lemel*, as the filings and turnings, etc., are termed, is purified by burning off organic matter, and then melting in a skittle-shaped crucible with suitable fluxes. The following may be taken as a general guide :—

Lemel	70 to 80 parts
Carbonate of soda	10 ,, 15 ,,
Common salt	. 5 ,,
Bisulphate of potash (sal-enixum) . .	. 2 ,,

Saltpetre may be used instead of the sal-enixum, but either of these salts should be sparingly employed. The common salt should not be mixed with the silver and other fluxes, but kept as a covering for the mixture, as it prevents the mass rising too much, and overflowing the crucible. The crucible should not be more than half full to commence with. After the whole mass has become liquid, keep it in fusion for about half an hour. Then allow the contents gradually to cool, and break the pot to recover the lump of metal.

Some manufacturers prefer to run down the "lemel" in an ordinary plumbago crucible, with carbonate of soda alone as the flux. When the metal is well fused, the mixture is well stirred with an iron rod from time to time, and the metal finally poured into an ingot-mould, ready for the refiner.

HALL-MARKING AND ASSAY OFFICES

§ 165. Standard silver is assayed and marked at certain duly authorised offices in various parts of the kingdom. The marks indicate the maker, quality of the standard, the place and year of assay, and the payment of duty. The name of the maker is indicated by his initials, the standard of 925 by a Lion Passant, the place of assay by heraldic arms, the year of assay by a letter, which is changed every year, and the payment of duty by the sovereign's head. There are seven assay offices, for which the arms are as follows: London, a leopard's head; Birmingham, an anchor; Chester, a sword between three garbs; Exeter, a castle with three towers; Sheffield, a crown; Newcastle-upon-Tyne, three castles, with the addition of a leopard's head; York, a cross and five lions, also with the addition of a leopard's head. There are two assay offices in Scotland, where the standard is indicated by the thistle. The distinctive marks are: Edinburgh, a castle; Glasgow, a tree growing out of a mount, with a bell pendant on the sinister branch, and a bird on the top branch, over the trunk of a tree a salmon *in fesse*, in its mouth an annulet. In Ireland the assaying and marking is restricted to Dublin. The standard of 925 and place of assay are indicated by a harp crowned; and the payment of duty by the figure of Hibernia, with an additional mark of the sovereign's head.

POLISHING, FINISHING, ETC.

§ 166. The beautiful lustre of silver is proverbial, as it is capable of receiving a most brilliant polish. The powders employed for polishing are: emery, pumice, rotton-stone, putty-powder (chiefly oxide of tin), crocus, rouge, etc., the latter being used for finishing. Scratches are often removed by a rather soft dark-gray stone, termed *Water-of-Ayr* stone. Emery and pumice are used for rough work to begin with, when the articles require much polishing. Oxide of iron, sold under the names of colcothar of vitriol, crocus, tripel, or rouge, contains much impurity, which cannot be removed by washing. [1] Vogel recommends the use of ferric oxide, prepared by the calcination of ferrous oxalate, as preferable to the ordinary levigated colcothar. Mr. Ross communicated to the Sc. of Arts, May 1833, the following receipt. Crystals of ferrous sulphate are to be dissolved in water, and the solution filtered to remove siliceous matter. To the filtered solution a saturated solution of soda is added, and the precipitate repeatedly washed and then dried. It is then gradually heated to dull redness in a crucible, and poured into a dish. On cooling it absorbs oxygen, and acquires a beautiful dark-red colour, when it is fit for polishing silver and gold. To fit it for polishing harder substances it must be heated to bright redness, and kept so until it acquires a purple hue on exposure to air. After this treatment it must be rubbed with a wrought-iron spatula on a wrought-iron slab, and afterwards levigated in a very weak solution of gum-arabic. It is then almost impalpable, free from foreign matter, and eminently suited for polishing steel, glass, the softer gems, etc.

No powder containing mercury should be used for polishing silver goods.

The surfaces of silver articles are improved in appearance by a process of "whitening," by which a pure snow-white colour is imparted, after every other process of workmanship has been completed. This enrichment is most perfect when the metal is of good quality, and the finish, as regards smoothness and freedom from solder-marks, of a high order.

Many different methods have been used. An old method is to dip the work in a thick solution of borax, then place it in a copper annealing pan, sprinkle it over with charcoal dust, and place the pan and its contents upon a clear fire. Heat until red-hot, then withdraw and allow to cool. The work is next boiled in dilute sulphuric acid, and if the right colour is not obtained the process is repeated one or more times. The lower standards require five or six operations to effect the proper degree of whiteness.

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[1] *Chem. Gazette*, 1854 (12), p. 410.

Another plan is to dip the work in a mixture of 4 parts powdered charcoal and 1 part nitre, well mixed with water. The work is heated until the coating is thoroughly dry, when it is removed from the fire, allowed to cool, and boiled out in a solution of bisulphate of potash. After two or three operations a beautiful dead-white colour is the result. It is then washed in soda and water containing a little soap, or "scratched" and burnished if required bright. The process is completed by drying in warm boxwood saw-dust.

[1] Gee's method of whitening consists of making the work red-hot, and boiling in dilute sulphuric acid (1 of acid to 40 of water). The process is repeated, if necessary, until the requisite colour is obtained. This method is not suitable for very common work, which requires a thin deposit of pure silver by the electro method, or by chemical decomposition of certain silver salts applied in the form of a paste, instead of subjecting it to the above whitening process. The articles may also be dipped in solutions containing silver, when silver is deposited on their surface. This is termed a "simple-immersion" process.

§ 167. **State in which Silver is Imported.**—"Silver bullion arrives in this country from America in various forms. That from Nevada and Canada is in rectangular oblong bars of various sizes, which weigh from 1000 to 1500 ounces each, and differ in content of silver from 100 to 999 per 1000, and which may or may not be free from gold. If 'dore' (*i.e.* such as contain gold), the proportion of gold rarely exceeds one-third of the weight, the alloy or base metal present chiefly consisting of copper and lead. The weight, assay produce, name of assayer, and value in dollars are usually stamped upon each bar.

"The metal is sold in the state in which it arrives, unless of low quality, when it is usually remelted here by one of the Bank of England melters. A large amount of silver comes from Mexico in the form of coined dollars, and is usually sold in that form for the China market, where the dollars are received as currency. Some Mexican dollars contain sufficient gold to pay for its extraction; and these are generally distinguished by certain letters upon them, specifying the mint in Mexico where they were coined, and they are assorted accordingly. Plata Piña is another form in which silver is imported into this country from Chili, Peru, and a few other localities; and such silver having been obtained by the process of amalgamation is generally in cylindrical or polygonal masses, according to the form of the moulds into which the amalgam was pressed before removing the mercury. Plata Piña sometimes contains gold, and is melted previously to sale in this market, when there is a loss of from 2 to 10 per cent, due to impurities. After fusion the metal is often 999 per 1000 fine.

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[1] *Silversmiths' Handbook*, p. 145.

"Silver is imported from South America in the state of coin, such as sols, Bolivian dollars, etc.; and in bars weighing 2000 to 3000 ounces each. These bars are either half-cylindrical or rectangular. The former are of good quality, varying from 995 to 999 per 1000 fine. The bars vary in fineness from 950 to 990, and are extremely hard, due to the presence of sulphur, arsenic, and antimony, which often render them very brittle. Up to 1875 these bars were melted on arrival and refined, as a necessary protection to the purchaser. They are now sold in the state in which they are received in order to save the cost of remelting."[1]

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[1] Percy's *Gold and Silver*, vol. i. pp. 301, 302.

CHAPTER XI

PLATINUM ALLOYS

§ 168. Platinum unites with most metals to form alloys, but in consequence of its high melting point, great difficulty is experienced in obtaining bodies of a definite composition containing volatile constituents. It should also be remembered that metals like silver and copper, which, under ordinary circumstances, do not vaporise, readily assume the gaseous state at the melting point of platinum. When a small quantity of platinum is heated with a large excess of a more fusible metal, the fusing point of the former is lowered sufficiently to enable it to melt and alloy with the latter at ordinary furnace temperatures. The alloys of platinum are, for the most part, much more fusible than platinum itself. When it is desired to alloy much platinum with another metal, a special arrangement, known as the oxy-hydrogen blowpipe furnace, is employed to effect the fusion.

Two well-fitting lumps of quicklime are hollowed out so as to form a cavity, in which the metal to be melted is placed. The cavity in the lower block is deeper than that of the upper one, as it has to contain the molten metal. The upper block is perforated through the centre with a hole, through which an oxy-hydrogen blowpipe passes, and a side opening between the two blocks permits the escape of the products of combustion, and serves as an outlet for the molten metal. The blowpipe is a double tube, the inner one conveying oxygen, and the outer one conveying hydrogen or coal-gas. The intense heat, produced by the burning of hydrogen in oxygen, is sufficient to melt a considerable quantity of platinum or platinum-alloy. In preparing an alloy, the platinum is melted first, and the other metal or metals then added through an aperture in the top of the furnace, which is then closed with a lime-plate.

The flame can be modified by means of stop-cocks to suit the conditions required. If the oxygen be in excess during the process of alloying with a base metal, the latter will be largely oxidised, so that it is advisable to have a slight excess of hydrogen to prevent this loss. The molten metal or the prepared molten alloy is cast into bars or ingots in moulds of lime, in suitable sizes for wire-drawing or rolling.

§ 169. **Platinum and Silver.**—These metals unite in several proportions, forming white or grayish-white alloys, which are harder and tougher than silver; and less fusible, malleable, and ductile, as the proportion of platinum is greater. There is a great tendency for the two metals to separate according to their specific gravities on cooling, the platinum settling to the bottom. Alloys with 17 to 35 per cent of platinum are used in dentistry, and known as *platine-au-titre.* These alloys are less readily tarnished than silver or ordinary silver alloys. Lewis in the last century prepared small quantities of the following platinum alloys:—

	I	II	III	IV
Silver . .	1	2	3	7
Platinum . .	1	1	1	1

The mixtures in I, II, and III required a strong white-heat for fusion; the products were hard and brittle in proportion to the contained platinum. The constituents of No. IV melted readily, and the alloy was harder, grayer, and of a coarser grain than silver; it hammered tolerably well. He found a considerable separation of platinum at the bottom of the moulds, unless the alloy solidified immediately on pouring.

[1] Berthier states that an alloy with 7 per cent of platinum is brittle, but Mr. E. Matthey denies the truth of this statement. An alloy of 37·5 per cent silver and 62·5 per cent platinum is said to have a colour half-way between silver and platinum, to flatten under the hammer, but to crack in rolling. With alloys low in platinum, nitric acid dissolves a certain quantity of platinum along with the silver. An alloy containing only 5 per cent of platinum dissolves completely in nitric acid. With sulphuric acid the silver only dissolves. When the above nitric acid solution is heated with sulphuric acid, the platinum separates out.[2]

Messrs. Johnson and Matthey prepare an extremely ductile alloy of 2 parts silver and 1 part platinum, as an article of commerce. This alloy has been adopted as a standard of electrical resistance.

Platinum and Gold.—See Gold Alloys.

§ 170. **Platinum and Copper.**—Alloys of these metals may be obtained by fusion of the constituents in all proportions. A high temperature is required for their production, the oxy-hydrogen furnace being required when the platinum is in excess. They possess considerable ductility, malleability, and tenacity; are capable of forming a variety of shades of colour, and are less tarnished by the atmosphere than alloys of copper with base metals. As the proportion of platinum increases the alloys become harder, whiter, and more brittle. They are capable of a high polish and have been used for the reflectors of telescopes.

When zinc is added in addition to copper, alloys are obtained nearly equal to gold in colour and lustre, superior in durability, and used in the manufacture of jewellery and ornaments.

An alloy of 1 part platinum and 4 parts copper is hard, ductile, of a yellow-pink colour, and susceptible of a high polish.

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[1] *Traité des Essais* (2), p. 800.

[2] *Handwörterbuch der Chemie* (7), p. 958.

An alloy of equal parts by weight of copper and platinum, according to Clarke, is yellow, having the colour and specific gravity of gold, extensible, easily worked by the file, and tarnished by exposure to air.

An alloy of 4 parts platinum and 96 parts copper is malleable, rose-coloured, and exhibits a fine-grained fracture.

An alloy of 3 parts platinum and 2 parts copper is nearly white, very hard, and brittle.

§ 171. The following alloys have a golden-yellow colour. No. IV, known as Cooper's gold, is malleable, ductile, and closely resembles 18-carat gold :—

	I	II	III	IV	V	VI	VII	VIII
Platinum .	18·2	5	29·3	18·75	57·7	66·7	29·1	19
Copper . .	45·5	...	66·7	81·25	38·5	29·1	66·7	81
Zinc . .	...	...	4	...	3·8	4·2	4·2	...
Silver . .	9	5	...	...	...	...	...	...
Brass . .	18·2	60	...	...	...	...	...	...
Nickel . .	9	30	...	...	...	...	...	...

Cooper's Mirror Metal.—Copper 57·85, platinum 9·49, zinc 3·51, tin 27·49, arsenic 1·66. The inventor claims for this alloy that it is indifferent to the weather, and takes a beautiful polish.

Cooper's Pen Metal.—The above alloy is said to be suitable for pens. Another alloy consists of copper 13 parts, platinum 50 parts, and silver 36 parts. The hardness and non-corrosive character of Cooper's alloys render them suitable for the manufacture of mathematical instruments and for chronometer wheels.

§ 172. **Platinum and Iridium.**—These metals unite in different proportions, but the intense heat of the oxy-hydrogen blowpipe is necessary to melt them and bring them into union. The alloy consisting of 9 parts platinum and 1 part iridium is used as a standard metal bar for the metric system. It is extremely hard, as elastic as steel, more difficultly fusible than platinum, perfectly unalterable in air, and capable of taking an exceedingly beautiful polish.

In the year 1870 Messrs. Johnson, Matthey, and Co. prepared a standard bar of the above alloy for the Parisian Commission for the International Metrical System, and after it had been subjected to every possible test which could be suggested in competition with other materials, it was, after two years' trial, pronounced the best, and adopted as the material for the manufacture of all the standard weights and measures.

The following alloys have been prepared by Deville and Debray, and their specific gravities determined:—

Platinum.	Iridium.	Specific gravity.
90	10	21·615
85	15	21·618
66·67	33·33	21·874
5	95	22·384

Specific gravity of platinum = 21·504; of iridium = 22·421. According to Deville and Debray, an alloy of 90 per cent platinum and 10 iridium has the same coefficient of expansion as the original metre preserved in the French Archives, which is known to have been made of impure platinum.

The 90 per cent platinum alloy is not attacked by aqua-regia.

Alloys with 20 per cent iridium are malleable and capable of being worked. An alloy of equal parts of the two metals is brittle, but capable of welding to some extent. An alloy of 1 part iridium and 10 parts platinum, when laid on copper, serves for metallic mirrors.

A native alloy of platinum and iridium is found in the Ural Mountains and in Brazil.

Platinum vessels for chemical operations generally contain iridium, which makes them stronger and harder.

§ 173. **Alloys of Platinum with easily fusible Metals.**—Platinum readily unites with *arsenic* and *antimony*, the combination being attended with vivid incandescence, forming brittle and easily fusible alloys.

Tin unites with platinum when the metals are fused together in equal parts, forming a hard, dark-coloured, somewhat fusible, brittle, and coarse-grained alloy.

Zinc unites with platinum forming an alloy of similar properties to the above-mentioned tin alloy.

Platinum and Lead readily unite, and very little lead makes platinum brittle. When molten lead is poured upon platinum, a portion of the latter is fused and dissolved in the lead. The alloys are hard, brittle, and granular.

Platinum and Bismuth form brittle alloys. Mr. Lewis found that the alloys ranging from 1 to 24 parts of bismuth to 1 of platinum are brittle, easily fusible, and have a laminar fracture. By contact with air they acquire a purple or violet tint. When moderately heated some of the alloys undergo liquation, the bismuth partially separating out. When strongly heated in air the bismuth largely burns off, forming bismuth oxide.

Platinum heated with *Cadmium* till the excess of the latter is volatilised forms a silver-white, very brittle, fine-grained alloy, refractory in the fire, and containing 46 per cent of platinum.

§ 174. *Platinum and Nickel.*—According to Lampadius, equal parts of nickel and platinum unite to form a pale yellowish-white alloy, perfectly malleable, susceptible of a high polish, equal to copper in fusibility and to nickel in magnetic power.

§ 175. *Platinor.*—This is a name given to certain alloys containing platinum, of a golden-yellow colour, and consisting of platinum, copper, silver, zinc, and nickel. An alloy of the colour of gold, and said to be quite constant in air, is prepared as follows: Melt 10 parts of silver with 45 parts of copper, then add 18 parts of brass and 9 parts of nickel. The temperature must then be raised to the highest pitch, and 18 parts of *platinum-black* added.

§ 176. *Platinum-Bronze.*—Several alloys of platinum, of a comparatively inexpensive nature, have been manufactured under the above name; and it has been claimed for them that they are indifferent to the action of the air and water. They admit of a high polish, and retain their lustre for a long time. The following table shows their composition and uses:—

Uses.	Parts.				
	Nickel.	Platinum.	Tin.	Silver.	Brass.
For table utensils .	90	·9	9	...	...
,, bells . .	81·5	·8	16	1·7	...
,, articles of luxury	86·5	·5	13	...	...
For tubes for telescopes, etc.	71	14·5	14·5	...	...
For ornaments .	31·6	3·2	...	...	65·2

CHAPTER XII

IRON AND STEEL ALLOYS

§ 177. The general impression in the past has been that alloys of iron are of little importance, which was due to an imperfect acquaintance with their nature and properties; but at the present time there is more light being thrown on the subject, and if we expand the idea of an alloy so as to include those compounds in which very small quantities of other metals, such as aluminium, are present, then the alloys of iron may be considered of very great importance.

As a rule, iron may be alloyed with most metals; but the combination is somewhat difficult to effect, and, in the majority of cases, only those alloys with a small quantity of iron, or iron with a small quantity of other metals, have been found to have useful applications. Iron, added to other metals or alloys, imparts new and sometimes important properties, such as increased hardness, elasticity, and tenacity. Many of the more recently discovered metals have of late years been added to iron with more or less marked alteration in its qualities, and such combinations are now ordinary commercial articles.

In the following description of iron alloys, the metals known as "malleable-iron," "cast-iron," and "steel" are not treated as separate metals, but considered as different varieties of iron.

§ 178. **Iron and Manganese.**—Our knowledge of the alloys formed by these metals has been greatly increased within the last few years by the labours of Mr. R. A. Hadfield of Sheffield. Iron readily unites with manganese, and when the proportion of the latter metal is considerable, the alloy is very hard, whiter, more fusible, and much more brittle in character than iron. In small quantity, up to ·4 or ·5 per cent, manganese is highly beneficial in steel, and some of the very best steel is that containing a little manganese. Steel containing from 2½ to 7 per cent of manganese is brittle and comparatively worthless, but when the amount exceeds 7 per cent, alloys possessing very great strength and toughness are obtained.[1] The weakness of the low percentage alloys may be understood from the following tests made by Mr. Hadfield. Cast-bars 2⅝ inches square and 30 inches long, supported on bearings 2 feet apart, were broken by hydraulic pressure. One specimen containing ·37 per cent of carbon and 4·45 per cent of manganese was fractured by a pressure of 3¾ tons, whilst a bar of ordinary cast-iron stood 12 tons, and bars containing 17 to 20 per cent manganese stood a pressure of 29½ and 38 tons respectively. A cast-bar containing 4·73 per cent manganese, when dropped from a height of 3 or 4 feet on to a cast-iron floor, broke in two or three places. A sample containing ·48 per cent carbon and 4·9 per cent manganese, though very ductile while hot, could be reduced to powder by a hand-hammer when cold, little or no cohesion seeming to exist between the particles. On the other hand, a specimen of forged material, containing 13·75 per cent manganese and ·85 per cent carbon, when water toughened had a tensile strength of 65 tons per square inch, with 50 per cent elongation; another specimen had a strength of 69 tons, and 46 per cent elongation. The strongest alloy contains about 14 per cent of manganese.

When manganese-steel is plunged into water no hardening effect takes place like that of ordinary steel, but the metal containing upwards of 7 per cent of manganese acquires increased tenacity and toughness. From a large number of tests it has been found that the higher the temperature to which the alloy is raised, and the more suddenly the cooling takes place, the higher is its breaking stress, and the greater its toughness and elongation. The influence of water quenching on manganese-steel is strikingly shown in alloys required to be drawn into wire. If it be attempted to draw hammered or rolled rods into wire without a previous heating and quenching it will not draw at all, and ordinary annealing makes no difference to it. If, however, it be raised to a yellow heat and then plunged into cold water it can be readily drawn into wire. After reducing the wire two numbers of the gauge, the metal is again heated and plunged into water. By this means it may be drawn to any reasonable degree of fineness.

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[1] Hadfield. Paper on Manganese Alloys. I. C. Eng. 28th February 1888.

The density of manganese-steel is a little higher than that of ordinary steel. In its ordinary condition it is very hard and easily scratches steel that is not highly tempered. When the manganese exceeds 20 per cent the alloy is practically non-magnetic. Dr. Hopkinson found that the maximum magnetisation of wrought-iron and manganese steel (with 12·36 per cent of manganese) are as 258 to 1. It shows no elongation under the magnetic influence.

Manganese-steel does not exhibit the anomalous expansion and "after-glow," termed *re-calescence*, which takes place in magnetic metals when they cool to a certain critical temperature, after being heated to whiteness. A Sheffield firm reported that in rolling a considerable length of manganese-steel, the finer it became the more it retained its heat, in fact, it appeared to gather heat in the process.

Ferro-Manganese is a variety of metal specially manufactured in a blast furnace from ores rich in oxide of manganese, and is very extensively used in the manufacture of mild steel. When the pig-iron contains less than about 20 per cent manganese, its fracture shows large crystalline cleavage planes, and it is then termed spiegel-eisen. The variety known as ferro-manganese is a hard, crystalline body, but the fractured surface does not present the large cleavage planes so characteristic of spiegel-eisen. It contains from 20 to 85 per cent manganese. For further information see the author's work on *Iron and Steel Manufacture* (Macmillan).

§ 179. **Iron and Nickel.**—These metals unite together to form a series of alloys which have lately received a good deal of attention; and although the most recent productions contain small quantities of other metals, such as manganese, they will be considered under this heading. Certain native alloys, occurring in aerolites, contain from 3 to 10 per cent of nickel. Faraday and Stodard prepared alloys of iron and nickel containing 3 and 10 per cent of nickel respectively. The former appeared to be as malleable, and could be as easily worked as pure iron. The latter was semi-ductile, very tenacious, with a granular fracture, and little affected by the atmosphere. They are capable of a high polish. Bergmann states that iron and nickel combine in all proportions. Lampadius states that an alloy of 5 parts nickel and 2 parts iron is moderately hard, easily malleable, and has the colour of steel.

Mr. James Riley of Glasgow and Mr. Hall of Sheffield have independently given considerable attention to iron-nickel alloys, and in a paper read by the former gentleman before the Iron and Steel Institute in May 1889, the following facts were stated: "The alloys can be made in crucibles or on a large scale in the Siemens's Open Hearth furnace, where a charge can be worked off in about seven hours. Its working demands no special care, and the composition of the resulting steel is easily and definitely controlled. If the charge is properly worked, nearly all the nickel is found in the steel, and almost none in the slag. The metal sets steadily in the mould; it is more fluid than ordinary steel when melted; it sets more rapidly, and appears thoroughly homogeneous. The ingots are clean and smooth in appearance on the outside, but those richest in nickel are a little more *piped* than are ingots of ordinary mild steel. There is less liquation of the metalloids in these ingots, therefore the liability to serious troubles from this cause is much reduced. The scrap produced in hammering, rolling, shearing, etc., can be remelted in making another charge without loss of nickel.

"If the steel has been properly made, and is of correct composition, it will hammer and roll well, whether it contains little or much nickel. It must be remembered, however, that in nickel-steel we have present nickel, manganese, and iron; with carbon, silicon, phosphorus, and sulphur, and that a difference in quantity of some of these will influence the character of the alloy; in other words, the degree of purity of the nickel and iron employed will modify the result, as in the case of ordinary iron and steel." The following table embodies the results of tests on various alloys made by Mr. Riley :—

Tests of Steel with varying Contents of Nickel.

No.	Composition per cent, exclusive of Iron.			Tensile Tests as Cast.					Tensile Tests as Cast and Annealed.					Tensile Tests as Rolled.					Tensile Tests as Rolled and Annealed.				
	Nickel.	Carbon.	Manganese.	Elastic limit in tons.	Breaking stress in tons.	Extension per cent in inches.		Contraction of area per cent.	Elastic limit in tons.	Breaking stress in tons.	Extension per cent in inches.		Contraction of area per cent.	Elastic limit in tons.	Breaking stress in tons.	Extension per cent in inches.		Contraction of area per cent.	Elastic limit in tons.	Breaking stress in tons.	Extension per cent in inches.		Contraction of area per cent.
						8 in.	4 in.				8 in.	4 in.				8 in.	4 in.				8 in.	4 in.	
1	1·0	·42	·58	Test-piece defective.					27·3	54·6	..	1·5	9·5	32·1	57·6	..	11·0	24	30·1	55·1	..	18·7	45
2	2·0	·90	·50	Too hard to machine with Mushet Steel. Makes a fine tool when tempered at a dull red heat in boiling water.																			
3	3·0	·35	·57	19·8	34·9	..	2·5	5·6	24·0	34·9	..	2·5	9·0	31·4	51·0	..	20·3	37·0	28·0	48·5	..	20·3	42
4	3·0	·60	·26	..	..	..	..	..	..	..	..	..	..	29·4	51·5	9·0	10·1	9·0	30·3	42·9	7·5	9·0	12
5	4·0	·85	·50	Too hard to machine with Mushet Steel. Makes a fine tool when tempered at a dull red heat in boiling water.																			
6	4·7	·22	·23	..	..	..	..	..	..	..	..	..	..	25·1	40·5	17·75	23·4	42·0	28·0	40·6	20·0	25·0	44·8*
7	5·0	·30	·30	..	..	..	..	..	..	..	..	..	..	30·0	46·4	10·0	12·5	22·5	28·0	42·6	15·0	17·5	18·5*
8	5·0	·5	·34	..	..	..	..	..	..	..	..	..	..	31·1	52·0	14·0	15·6	14·0	32·5	46·8	13·5	14·0	17·0*
9	10·0	·5	·5	Too hard to machine. Makes a good cutting tool when tempered in cold air-blast.																			
10	25·0	·27	·85	..	..	..	..	..	..	..	..	..	..	38·2	51·4	10·5	11·7	..	12·75	45·8	29·0	30·0	28·6
11	25·0	·82	·52	..	..	..	..	..	..	..	..	..	..	22·0	47·6	43·5	47·6	60·0	15·1	42·1	40·0	45·3	43·6
12	49·4	·35	·57	..	..	..	..	..	..	..	..	..	..	20·5	37·4	..	12·0	24·0	21·0	37·0	..	20·0	29·0

* Average reduced by one piece giving low result.

It will be seen from the foregoing table that the addition of nickel to mild steel increases the elastic limit and breaking stress considerably. In Nos. 2 and 5 tests the extreme hardness, partly due to the large amount of carbon, is also increased by the presence of nickel. In No. 9 test, with much less carbon, but with 10 per cent nickel, a very hard alloy is obtained. This quality of hardness continues as the nickel is increased, until about 20 per cent is reached, when a change takes place, and successive additions of nickel tend to make the steel softer and more ductile. With regard to the hardening effect of nickel on iron there is some resemblance to the manganese-steel previously described. The whole of the series of nickel-steels up to 50 per cent nickel take a good polish and finish, with a good surface, the colour being lighter with the increased additions of nickel.

Mr. Riley states that the steels rich in nickel are practically non-corrodible, and that those poor in nickel are much better than other steels in this respect. The 1 per cent nickel-steel welds fairly well, but this property deteriorates with each addition of nickel. Mr. Hall states that the alloys of nickel and iron are among the most powerful connected with the magnet that he has seen or heard of. The conductivity for electricity of iron-nickel alloys is extremely low, and the electric resistance extremely high.

The alloys of iron and nickel may be prepared by melting iron and nickel together; by reducing oxide of nickel with carbon in the presence of iron; or by adding ferro-manganese to molten iron and nickel to obtain nickel-steel. Mr. Riley states that without the aid of manganese the conditions of treatment would not be successful.

§ 180. **Iron and Cobalt.**—According to the experiments of Brande and Bergmann, these metals combine in all proportions. The alloys are said to be hard, and as ductile as iron. Hassenfratz has shown that iron containing cobalt can be forged and welded, and although a little brittle when hot, it is not so when cold. According to Berzelius, the alloys of these metals are hard and magnetic. It is probable that the action of cobalt on iron is much the same as that of nickel, judging from the similarity of cobalt to nickel in many of its physical and chemical properties.

§ 181. **Iron and Molybdenum.**—Dr. Thompson considers that of all the metals, molybdenum is the one with which iron unites most readily. With equal parts of the two metals the alloy is fusible with the blowpipe. With 1 part iron and 2 parts molybdenum, an alloy of a clear grayish-white colour is obtained. An alloy of 20 per cent molybdenum is whiter than iron, very hard, brittle, tenacious, and has a granular fracture. Berthier considers the alloys of molybdenum and iron to be in every respect the analogues of those of tungsten and iron. They are generally grayish-white, hard, brittle, fine-grained, and magnetic. When the molybdenum is below 50 per cent the alloys are somewhat fusible. Copper blast-furnace *bears* (as the metallic masses found in the hearths of old copper blast-furnaces are termed) chiefly consist of iron and molybdenum.

§ 182. **Iron and Chromium.**—These metals have a strong affinity for each other and appear to form alloys in all proportions. Chrome-iron ore is somewhat abundant in nature, and when such ore is submitted to a reducing influence at a high temperature both iron and chromium occur in the reduced metal. Berthier states that when a mixture of oxide of iron and oxide of chromium is strongly heated in a carbon lined crucible, both oxides are completely reduced, and a perfectly homogeneous combination of the two metals is obtained. The alloys are generally hard, brittle, crystalline, of a grayish-white colour, and having a considerable lustre; less fusible, less magnetic, and less soluble in acids than iron; the characters are the more prominent in proportion to the amount of chromium present in the alloys.

[1] In 1820 Faraday produced two specimens of chrome-

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[1] *Quarterly Journal of Science*, 1820.

steel. He states that both forged well, and were as malleable as pure iron, and that both gave a very beautiful damask when rubbed with sulphuric acid. From these results as to malleability, and also from the mixture used, the percentage of chromium must have been small. This *damascening* of chrome-steel is interesting when we consider that it is not producible with ordinary steel, and that it is only otherwise produced by taking extreme precautions in the working of the purer forms of malleable iron. [1] Schneider has shown that chrome pig-iron is not a homogeneous body, and the fact of the damascening being produced in the steel would indicate that the observation would also apply to it. Two alloys prepared by Berthier, one containing ·1 and the other ·15 per cent chromium, forged well, and made razor and sword blades of excellent quality.

M. Brustlein, of Unieux, France, commenced the manufacture of chrome-steel in 1875. Ferro-chrome is produced in crucibles and a certain proportion of this rich alloy is added to the steel. The usual specimens of the ferro-chrome contain from 42 to 52 per cent of chromium. The metal is cast into iron moulds and chilled. The following table shows the composition per cent of different samples; and it is interesting to notice the large amount of carbon taken up by the alloys :—

	Per cent.							
Chromium	80	66	52	42	25	18	16	12
Carbon	11	9·5	7·8	7·3	6·7	6·2	2·7	2

The remainder would be iron and silicon, the latter sometimes exceeding 2 per cent. The hardness and brittleness increase with the proportion of carbon and silicon. When ferro-chrome is cooled slowly it crystallises into a mass of needle-shaped crystals, which are more apparent when the carbon is low.

With regard to magnetism, chromium has a much less powerful effect in destroying the magnetic properties of iron than manganese, for iron containing 65 per cent of chromium is still attracted by a magnet.

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[1] *Oesterreichische Zeitschrift für Berg und Hüttenwesen*, 1886, tom. xxxiii. p. 29.

In the manufacture of steel, varying proportions of chromium may be used. Brustlein states that steel containing 2 per cent carbon and 12 per cent chromium may be forged. The presence of chromium in steel increases its tenacity and imparts a higher resistance to pressure. It also renders steel harder to file or work on the lathe in proportion to the quantity of carbon present. Hardened steel containing chromium has a very fine grain, and breaks with a glassy fracture. Chrome-steel cannot be welded; it burns when highly heated, owing to the strong affinity of chromium for oxygen, and the oxide formed is infusible even at the melting-point of steel. From the above table it will be seen that ferro-chromes may be combined with exceptionally large proportions of carbon, and they may in consequence be used instead of ferro-manganese in making Bessemer or Siemens's steel. But extra soft steel, containing much chromium, is at present impossible. If ferro-chrome be made, having little carbon, it is very oxidisable, and almost infusible, so that many difficulties stand in the way of supplanting ferro-manganese by ferro-chrome.

§ 183. **Iron and Titanium.**—Pig-iron sometimes contains titanium, when obtained from ores containing that metal, which often occur along with iron ores. The titanium is either minutely disseminated through the iron or alloyed with it. Some analyses by Mr. Riley of gray pig-iron from Wiltshire gave 1·15, ·71, and ·47 per cent of titanium respectively. But iron smelted from titaniferous iron-ore may be quite free from titanium. [1] In 1877 Mr. Riley showed that the so-called titanium steel of Mushet[2] contained no titanium. Faraday failed to reduce titanium oxide, although he states that rhodium, and, imperfectly, platinum were melted in the crucibles he used. In 1742 Mr. Horne successfully smelted the titaniferous ores of Canada, and good steel was made from them, the virtue of which was ascribed to this particular ore, although this was before titanium had been isolated as an element. It is a noted fact that titanium iron ores are practically free from phosphorus, which may readily account for the good quality of iron produced therefrom. We may consider then that titanium steel exists only in name. What titanium occurs in the pig-iron passes into the slag when the iron is refined.

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[1] Iron and Steel Institute, 1887.

[2] Mushet's patents, 1859 to 1861.

§ 184. **Iron and Tungsten.**—These metals unite to form some valuable alloys. Steel containing tungsten is highly valued for cutting tools. Formerly, the oxide of tungsten and carbon were melted in crucibles with Swedish or good hematite pig-iron. The steel is now made by introducing a rich alloy, containing up to 50 per cent of tungsten, into the crucible or bath of metal. Tungsten steel is known in England as Mushet's special steel. It possesses a natural hardness of its own, and, when upwards of 3 per cent of tungsten is present, instead of being hardened by heating and quenching in water, like ordinary steel, it is actually softened. It is very difficult to forge, and cannot be welded when the tungsten exceeds 2 per cent; but can be cast into the form of tools, which can be ground to a fine edge. Tungsten gives to steel a very fine and uniformly crystalline structure, and such steel is less affected by the atmosphere than ordinary steel. [1] Mr. Stroh states that tungsten-steel possesses remarkable magnetic properties. He uses a 3 per cent tungsten alloy for telephone magnets with marked advantage. It is stated by several experimenters that tungsten imparts to cast-iron great hardness and tenacity, but Guettier found no advantage in adding tungsten to cast iron as regards resistance to shock or flection. The general concensus of opinion appears to be that tungsten in steel is valuable for certain purposes, but that the general method of obtaining it is too expensive to make its manufacture on an extensive scale a commercial success. Sieward examined six samples of tungsten steel: four of them contained from ·1 to 3 per cent tungsten, while none was found in the other two. The best results are obtained when the alloy is reduced from iron ores containing a little tungsten oxide. The difficulties in making stable alloys with tungsten are increased in consequence of its high melting point, and high specific gravity.

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[1] *Transactions of Soc. of Telegr. Eng.* 1882.

§ 185. **Iron and Copper.**—[1] Guettier states that the alloys of iron and copper are difficult to procure by direct fusion of the metals. The copper remains in a pulverulent state within the iron, has a tendency to become precipitated to the bottom of the fluid mass, or in the moulds, and the combination is generally incomplete. Copper imparts to cast-iron a grayish lustre, probably due to uncombined copper.

Copper is considered very injurious in iron and steel even when present in minute quantity, but the late Mr. Willis of Landore stated that ·1 per cent of copper produced no appreciable effect on the quality of steel. The injurious effects attributed to copper are very marked when sulphur is present in notable quantity, making the metal red-short. M. Choubly of the Firminy Steel Works has experimented on phosphoric steel containing copper, and he states that a metal containing ·5 per cent of carbon, ·15 phosphorus, ·04 sulphur, and 1 copper rolled perfectly well.

[2] Messrs. Ball and Wingham have investigated the influence of copper on the tensile strength of iron and steel. An alloy containing—

Copper	7·550
Carbon	2·720
Manganese	·290
Silicon	·036
Phosphorus	·130
Sulphur	·190

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[1] *Guide Pratique des Alliages*, 1865.

[2] Iron and Steel Institute, May 1889.

was bright, white in colour, crystalline, and very hard, but did not offer any great resistance to impact. Varying quantities of the alloy were melted down with Bessemer steel, and test pieces 1 inch by $\frac{1}{4}$ inch by $\frac{3}{16}$ inch were annealed and tested. The following table shows the results:—

No.	Copper.	Carbon.	Tensile strength.
1	·847	·102	18·3
2	2·124	·217	36·6
3	3·630	·380	47·6
4	7·171	·712	56·0

From these experiments it is clear that copper increases the tensile strength of iron. The simultaneous presence of carbon assists in the more intimate association of copper with iron. In test-piece No. 1 the fractured surface was somewhat fibrous, while No. 2 and the others were highly crystalline. Even in the absence of carbon copper makes iron extremely hard.

Mr. F. Stubbs states that the presence of $\frac{1}{2}$ per cent of copper in steel gives it the property of preventing the oxidation of the steel on being subjected to a burning heat.

§ 186. **Iron and Tin.**—These metals may be alloyed together in several proportions, but the combinations are brittle, and the fusing-point diminishes with the proportion of tin. A small quantity of iron in tin imparts greater hardness and a duller lustre. A small quantity of tin in iron renders it cold- and hot-short. Cast-iron containing tin may have as fine a fracture as that of steel. It becomes black, is capable of a fine polish, and less tarnished in air than ordinary cast-iron. A proportion of 2 per cent of tin in cast-iron renders the metal dry and brittle, and the iron puddled from such pig-iron is hard and less malleable. The following alloys have been studied by Guettier[1]:—

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[1] *Guide Pratique des Alliages*, 1865.

	I	II	III	IV
Iron . .	30	50	70	90
Tin . .	70	50	30	10

No. I has a dark-gray fracture, and is somewhat ductile.

No. II is white, brittle, and has a granular fracture.

No. III is crystalline, with an iron-gray texture, and may be pulverised under the hammer.

No. IV is light-gray. The grain, which is dry and without lustre, is filed with great difficulty. It is very brittle and hard. It has a fine lustre when polished, and is grayish-white in colour.

An alloy of iron and tin is said to be preferable to pure tin for tinning copper vessels.

§ 187. **Iron and Zinc.**—These metals unite together to form a series of alloys which are hard, more or less crystalline, and brittle. The difficulty of forming alloys by direct fusion is owing to the high melting point of iron, and the volatile character of zinc. Greenwood states that 7 per cent is the maximum amount of iron that zinc will take up, but Guettier states that he obtained alloys containing 50 per cent of zinc and upwards by pouring zinc down an iron tube into a bath of molten cast-iron. The alloys became whiter and slightly more malleable as the proportion of zinc was increased.

§ 188. **Iron and Aluminium.**—These metals unite in various proportions, forming hard, white, and brittle alloys when the aluminium is present in notable quantity. Alloys, known as "ferro-aluminium," have been somewhat largely made of late years, and used for introducing small quantities of aluminium into steel and cast-iron instead of adding the pure metal. When the aluminium in the ferro-alloys exceeds a certain amount (about 17 per cent), the alloy becomes non-magnetic, and like ferro-manganese, is not attracted by a magnet. Aluminium added to molten iron and steel lowers their melting points, increases the fluidity of the metal, and causes it to run more easily into moulds and set solid, without the formation of blowholes. Mr. Nordenfelt adds a small quantity of aluminium to wrought-iron, which lowers the melting point sufficiently to enable it to be poured like ordinary cast-iron. The Cowles Electric Smelting Company are now manufacturing large quantities of ferro-aluminium, and they claim that this alloy is perfectly homogeneous, and that when a ladleful of molten steel is poured on a portion of the metal, the aluminium is equally distributed throughout the whole mass. The effect of a small portion of aluminium on steel is to raise its elastic limit and ultimate strength, as well as to impart the properties mentioned above.

The effect of aluminium on cast-iron has been studied by Mr. Keep of Michigan,[1] who states that the appearance of the fracture is a strong indication of the character of the metal, and that a bar ½ inch square, more than any other size, shows by a change of the grain the effect of varying composition. A smaller bar chills so quickly that it does not give an element sufficient time to exert its influence, while a larger bar holds its heat so long that any tendency towards a white grain is more or less overcome. Mr. Keep commenced his tests with a pig-iron containing 1·27 graphite, 1·71 combined carbon, and ·08 silicon, which gave castings full of blowholes. To a portion of this pig-iron ferro-aluminium was added, so as to produce a metal containing ·25 aluminium, 1·37 graphite, and ·2 silicon per cent. The result was a more even grain, with absolutely no blowholes. The silicon had increased, and added to the hardness of the casting.

With the addition of silicon alone to the above pig-iron, a casting was obtained nearly as sound, but not so strong, especially in its resistance to shock. The effect of aluminium on white or mottled pig-iron is to convert combined carbon into graphite, as silicon does, but without weakening effects. When the pig-iron contains its carbon entirely in the form of graphite, there is no advantage in adding aluminium. Mr. Keep states that aluminium of itself does not add to the strength of cast-iron, but, through its influence on the carbon, does increase the strength of the iron indirectly. Now as aluminium causes combined carbon to pass into graphite when the metal is remelted, some of the separated carbon rises to the surface, and is removed entirely from the cast-iron, and the strength of the casting is thus increased. Irons made gray by aluminium are valuable for the making of thin castings, where strength as well as softness is desired.

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[1] See *Proceedings of American Assoc. for Advancement of Sc.* August 1888, and *Proceedings of Amcrican Institute of Mining Engineers*, 1889.

The introduction of aluminium into molten cast-iron is attended with serious difficulty. If ferro-aluminium, broken into small pieces, is introduced into the ladle before the metal is "caught," it will be melted as the first iron strikes it; but if plunged into the iron after the iron is caught, it is likely to chill a coating of iron around it. In this condition the metal swims. Pure aluminium thrown on the molten iron melts at once, and sinks into the metal, but the whole does not seem to remain in the iron, as it does when successfully introduced in the form of ferro-aluminium. Aluminium introduced into the foundry ladle in the smallest quantities causes the iron to boil rapidly, probably because of the particles of graphite which it liberates. This ebullition is so rapid that slag which has risen to the surface is often carried under again by the force of the current.

CHAPTER XIII

MISCELLANEOUS ALLOYS

§ 189. **Alloys for Calico-printing Rollers and Scrapers.**—For this purpose a metal is required that is sufficiently soft to be worked by tools, and hard enough to resist the wear to which it is subjected in practice. Another important desideratum is that the metals should be capable of resisting the corrosive action of the liquids with which they are in contact. Hauvel considers a bronze having the following composition the best material for the rollers: copper 84, tin 14, zinc 2. Another alloy which is used consists of zinc 78·5, tin 15·8, copper 5·6. The following are analyses by Dépierre and Spiral of the scrapers employed to remove the surplus colour from the rollers:—

	Copper.	Zinc.	Tin.
French scrapers . . .	78·75	12·50	8·75
English ,, . . .	80·50	11·50	8·00
German ,, . . .	85·30	9·80	4·90

The Société Industrielle de Mulhouse many years ago offered a premium for the best alloy for the above purpose. It must possess at the same time elasticity and toughness, hardness and flexibility, without being sensibly attacked by the chemicals used in printing. Messrs. Dépierre and Spiral classify the alloys for scrapers into three groups: (1) copper, with 95 to 100 per cent of copper; (2) brass, with about 60 per cent copper and 40 per cent zinc; (3) brass, containing notable proportions of lead and tin. The following table shows the physical properties of the alloys examined by these experimenters :—

TABLE I

Sample.	Colour.	Class.	Density.	Grain.	Hardness.	Remarks.
1	red	1	8·22	coarse	hard	. .
2	,,	1	8·83	fine	,,	. .
3	,,	1	8·82	coarse	very soft	. .
4	,,	1	8·83	very fine	medium	. .
5	yellow	3	8·40	coarse	hard	blow-holes.
6	,,	2	8·25	very fine, homogeneous	,,	. .
7	,,	3	8·58	fine, not homogeneous	very brittle	. .
8	red	1	8·88	very fine	hard	burnt.
9	,,	1	8·80	coarse	soft	suitable for printing.
10	yellow	2	8·15	very fine	hard	very unequal
11	,,	3	8·45	coarse, homogeneous	,,	. .
12	,,	3	8·5	fine, not very homogeneous	very brittle	many blow-holes.
13	red	1	. .	. .	. .	very good.
14	,,	1	8·9	fine	hard	bad.
15	yellow	3	8·35	,,	,,	very good.
16	,,	3	8·20	,,	,,	blow-holes.
17	,,	2	8·10	fine, homogeneous	,,	very bad.
18	red	1	8·9	fine	,,	good.
19	. .	. .	. .	. .	. .	. .
20	yellow	2	8·20	coarse, not very homogeneous	soft	. .
21	,,	2	8·15	fine, homogeneous	hard	. .
22	,,	2	8·22	medium	soft	. .
23	red	1	8·85	fine	hard	. .
24	yellow	2	. .	. .	. .	. .
25	grayish-yellow	3	. .	. .	. .	attacked by colours.

The following table shows the composition of the alloys whose properties are given in Table I :—

TABLE II

	No. of the samples.	Copper.	Tin.	Lead.	Zinc.	Remarks.
Copper.	3	99·16	·15	·12	·57	...
	4	99·16	·02	·12	·58	Some aluminium.
	8	99·13	·03	·19	·45	Some aluminium and sulphur.
	9	99·03	·03	·12	·60	Some aluminium and sulphur.
	1	99·03	...	·14	·67	Some aluminium and sulphur.
	2	99·67	...	·07	...	Some aluminium and sulphur.
	14	99·40	...	·48	...	...
	18	99·84	...	...	...	...
	23	99·52	...	...	...	...
Brass.	6	60·33	·03	·68	38·68	All contain traces of arsenic.
	10	61·70	·08	·64	37·51	
	20	64·41	·21	2·86	31·88	
	22	68·60	...	·39	30·53	
	21	58·25	...	·43	41·02	
	17	77·68	...	·42	21·41	
Brass alloys.	11	74·51	2·80	2·18	19·85	
	12	76·96	2·55	1·88	17·83	
	7	77·63	2·58	1·94	17·16	
	5	74·12	2·37	2·22	20·59	
	15	79·42	4·17	1·23	14·49	
	16	72·15	3·27	1·71	22·16	
	24	70·40	...	·60	28	
	25	15·00	...	...	84	

Besides the copper series, the alloys containing 25 to 30 per cent zinc, and 75 to 70 per cent copper are especially suitable for rollers. Even so small a content of lead as ·5 per cent exerts an injurious influence, and the samples containing lead showed blow-holes. Messrs. Dépierre and Spiral are of opinion that rolls of copper containing 1 to 2 per cent of phosphorus would yield excellent results as regards resisting chemical influences, as well as giving hardness, fineness of grain, homogeneousness, and durability. An addition of 1 per cent phosphorus might also be recommended for varieties of brass containing 30 to 35 per cent of zinc.

§ 190. **Alloys said to be Non-oxidisable.**—*Lemarquand's alloy* is said to consist of: copper 75, nickel 14, cobalt 15, tin 18, and zinc 72 parts. The metals must be pure. *Marlie's alloy* consists of: iron 10, nickel 35, brass 25, tin 20, zinc 10. Articles prepared from this alloy are made white hot, and dipped into a mixture of sulphuric acid 60 parts, nitric acid 10, hydrochloric acid 5, and water 25.

An alloy used as a substitute for gold and said to be non-oxidisable was found by the author to contain: copper 94·8, zinc 2·8, lead ·67, and iron 1·34 per cent. The inventor recommends to dip the articles in dilute nitric acid, then to swill and dry, then to polish; and claims that they will keep their colour for a long time.

A new alloy has been prepared by Herr Reith of Bockenheim, Germany, and is said to practically resist the attack of most acid and alkaline solutions. It consists of: copper 74·5, tin 11·6, lead 9, antimony 4·9 parts. This alloy is therefore a bronze with the addition of lead and antimony. The inventor claims that it can be very advantageously used in the laboratory to replace vessels or fittings of ebonite, vulcanite, or porcelain.

§ 191. **Amalgams for silvering Glass Globes.**

Lead.	Tin.	Bismuth.	Mercury.
1	1	1	1
1	1	1	2

The lead and tin are melted first, after which the bismuth is added. The dross is scraped off, and the mercury added, when the whole mixture is well stirred. Leaves of Dutch-metal are sometimes added, according to the colour which it is desired to impart to the globes.

§ 192. **Gersnein's Alloy,** for making a soft mastic for uniting glass, earthenware, etc. It becomes so hard after a time that it may be polished like silver. 25 to 35 parts of precipitated copper are ground with strong sulphuric acid in a porcelain mortar, and then 65 to 70 parts by weight of mercury are gradually added. When the copper is amalgamated it is well washed in boiling water. Whenever it is desired to employ it as a mastic, it is made soft and plastic by heating to about 375° C. and well grinding in a mortar until it is soft. It is insoluble in weak acids, alcohol, ether, or boiling water. It has been also employed by dentists for filling teeth.

§ 193. **Sideraphite.**—A new alloy, which resembles silver, and is very ductile and malleable, is composed of 63 parts of iron, 23 of nickel, 4 of tungsten, 5 of aluminium, and 5 of copper. The iron and the tungsten are melted together and then granulated, and the water into which the mixture is poured for this purpose must contain 1 lb. of slaked lime, and the same quantity of potash, to every gallon. The product formed by the fusion of the nickel, copper, and aluminium is also granulated in water containing the same proportion of lime and potash; and, during the melting the metals in the two crucibles must be kept covered with a flux made of two parts of borax and two of saltpetre. A piece of soda or alkali, weighing about the $\frac{1}{2500}$ part of the whole mass, is to be put into the crucible containing the copper, nickel, and aluminium, in order to prevent the oxidation of the last-named metal; and, to prevent the same action taking place with the copper, a small piece of charcoal is added. It is advisable before the operation of granulation to well stir the contents of the two crucibles. The granulated metals are dried, melted in the proportion given above, well shaken, and then run into bars. The new alloy, to which the name of *sideraphite*, or changeless iron, has been given, is said to have the appearance of silver or platinum, and not to be dearer than ordinary white metal. It will resist the action of sulphuric acid, is not attacked by the organic acids, and very slightly so by the inorganic acids.

§ 194. **Alloy for Horology.**—The following alloy, suited for the sockets of pivots of watches, was invented by Mr. Bennett. It consists of—gold 31 parts, silver 19, copper 39, and palladium 11. He states that this alloy melts at a lower temperature than gold, and is harder than hammered iron. It has a reddish-brown colour, is as fine-grained as steel, and works as easily as brass, but its friction is much slighter than on ordinary pivots. Its most valuable property is—that the oil it absorbs is not decomposed, but remains pure, in a fluid state. It has still greater advantages over sockets of fine stone, as it is not apt to break, is susceptible of a high polish, and is less costly than hard stone.

For other miscellaneous alloys see also p. 338.

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